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Measuring Climate and Extreme Weather Vulnerability to Inform Resilience, Report 2 : Port Decision-Makers' Barriers to Climate and Extreme Weather Adaptation

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Measuring Climate and Extreme Weather Vulnerability to Inform Resilience

Report 2: Port Decision-Makers' Barriers to Climate and Extreme Weather Adaptation

Elizabeth L. Mclean and Austin Becker

November 2019

Cover photo: Ship transits on Elizabeth River in Norfolk, VA, by Elizabeth Mclean

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Measuring Climate and Extreme Weather Vulnerability to Inform Resilience

Report 2: Port Decision-Makers' Barriers to Climate and Extreme Weather Adaptation

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Report 2 of 2

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Abstract

Numerous decision-making barriers prevent or delay climate and extreme weather resilience investments. Port decision-makers' perceptions of such barriers are important for proactive strategies for reducing coastal vulnerability and supporting safe and sustainable operations of U.S. ports.

This report identifies the perceived adaptation barriers for seaports, and strategies to remove them. Interviews with 30 directors/managers, environmental specialists, and safety planners at 15 medium- and high-use ports of the North Atlantic resulted in a typology of factors and conditions that hamper adaptation actions, planning, and perceived strategies to overcome these barriers.

This study finds that the decision-makers have consensus on seven overarching barriers to adaptation: the lack of understanding of the risks (93%), lack of funding (77%), perceived levels of risks do not exceed the action threshold (70%), governance disconnect (67%), physical constraints (67%), lack of communication amongst individuals (7%), and the problem (of adaptation) is overwhelming (7%).

For strategies to overcome the adaptation barriers, the study points to the importance of fostering collaborations, making regulatory changes, and conducting risk assessments. Port decision-makers also mentioned the need for developing financial incentives and taking advantage of communication networks as necessary strategies to implement climate and extreme weather adaptations.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE), Navigation Systems (NavSys) Research Program. NavSys is administered at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), under the USACE Navigation Research and Development Program. The Program Manager of the NavSys Program was Mr. Charles E. Wiggins. This contract report was prepared by an interdisciplinary team at the University of Rhode Island, Kingston, RI, at the direction of Dr. Julie Rosati and Ms. Katherine Chambers at the ERDC-CHL, Vicksburg, MS, and was funded by the Broad Agency Announcement Category CHL-11: Coastal Inlets and Navigation Channels. A full proposal was submitted to the ERDC-CHL, Vicksburg, MS, through the Vicksburg Consolidated Contracting Office. This work was performed under Work Unit 33143; Project W912HZ-16-C-0019.

At the time of publication of this report, Mr. Jeffrey R. Eckstein was the Deputy Director of ERDC-CHL, and Dr. Ty V. Wamsley was the Director.

COL Teresa A. Schlosser was the Commander of ERDC, and the Director was Dr. David W. Pittman.

Executive Summary

Stakeholders of the maritime transportation system are becoming more aware of the importance of building and strengthening the resilience of coastal infrastructure. Heavy rains, storms, sea level rise, and extreme heat damage coastal critical infrastructures (Melillo et al. 2014). The frequency, intensity, timing, duration, and location of such climate and extreme weather events will define how the U.S. maritime transportation system experiences future impacts. However, information on barriers to building resilience for ports is limited.

Climate change studies stress that decision-making barriers slow the development and implementation of much-needed adaptation strategies (Moser and Ekstrom 2010; Biesbroek et al. 2011). For this reason, examining decision-maker perceptions of adaptation barriers is key to the implementation of plans and effort to reduce risks and build the resilience of ports.

Barriers are defined as factors or conditions that impede, prevent, or delay processes for the development and implementation of climate change adaptation strategies (Biesbroek et al. 2011). Barriers to resilience investment include underestimating true risk levels, lack of financing, lack of awareness, and misaligned incentives (Moser and Ekstrom 2010; Biesbroek et al. 2011). At the national and global levels, trade and development rely on the efficient operation of maritime transportation[1]. Still, decision-makers have not yet made sufficient investments towards climate and extreme weather resilience (Biesbroek et al. 2011), as seen recently with the aftermath of Hurricane Sandy at the port of New York and New Jersey (Greene et al. 2013; Becker et al. 2014; Becker 2016; Ng et al. 2016), and earlier in Gulfport, MS, during Hurricane Katrina (2005) (USDOT 2013). Differences in stakeholders' risk perceptions can be a source of conflict in the deliberations and planning. This research focuses on identifying the perceived barriers and how three categories of key port decision-makers think about those barriers, as well as about the strategies needed to overcome them.

[1] Asariotis, R., H. Benamara, and V. Mohos-Naray. 2017. *Port Industry Survey on Climate Change Impacts and Adaptation*. UNCTAD Research Paper No. 18. United Nations Conference on Trade and Development.

This study characterizes the barriers to climate and extreme weather adaptations for ports and suggests approaches to develop adaptation strategies that encourage long-term resilience planning. Adaptation strategies minimize vulnerability to natural hazards (Nicholls et al. 2008). Reactive mitigation, currently the dominant adaptation strategy (Measham et al. 2011), leaves coastal communities at risk and threatens the stability of their economy, environment, and human safety. Hence, seaport planners and managers need to plan, implement, and monitor pro-active adaptations to enhance the resilience of these ports (DHS 2009).

This work is part of the U.S. Army Corps of Engineers (USACE) Project W912HZ-16-C-0019 entitled "Measuring Climate and Extreme Weather Vulnerability to Inform Resilience." This report captures the first of a two-part study. In the first part of the study (McIntosh et al. [2019], *Measuring Climate and Extreme Weather Vulnerability to Inform Resilience: Report 1: Pilot Study for North Atlantic Medium- and High-Use Maritime Freight Nodes*), experts ranked higher the use of *exposure* and *sensitivity* indicators as measures of ports vulnerability. This report is a summary of the second part of the study. It focuses on *adaptive capacity* — the third component of vulnerability — and in particular on barriers to adaptation. To identify seaport decision-makers' perceived barriers to adaptations, port directors/managers, environmental specialists and safety planners in 15 of the 22 medium- and high-use ports of the USACE North Atlantic Division were interviewed. Researchers also asked decision-makers about resources and strategies that could help remove the barriers to adaptation. A cultural consensus model (CCM) characterizes the barriers identified during the interviews within the larger context of the port community's resilience. The CCM measures levels of agreement for the top barriers identified by the participating decision-makers.

Outlining how the decision-makers perceive those barriers is fundamental for implementing actions to reduce risk and enhance the port's resilience. Climate change studies stress that decision-making barriers slow the development and implementation of much-needed adaptation strategies (Moser and Ekstrom 2010; Biesbroek et al. 2011). Other studies have relied on stakeholders' views to assess flood risk (Van Kleef et al. 2007), impacts of sea level rise (SLR) (Poumadère et al. 2008), as well as how stakeholders are impacted by the strike of storms (Becker et al. 2014). Already, ports and critical coastal infrastructures are damaged by heavy rains, storms, SLR, and extreme heat damage (Melillo et al. 2014). To illustrate the challenge of adaptation, Moser and Ekstrom (2010) defined how the barriers can appear in different phases, from (1) the Understanding phase, (2) the Planning phase, and (3) the Management phase. Some studies indicate that there will always be barriers to adaptation, but that, different from a limitation, by definition, a barrier can be overcome through planning efforts, creative thinking, and the prioritizations of resources (Moser and Ekstrom 2010).

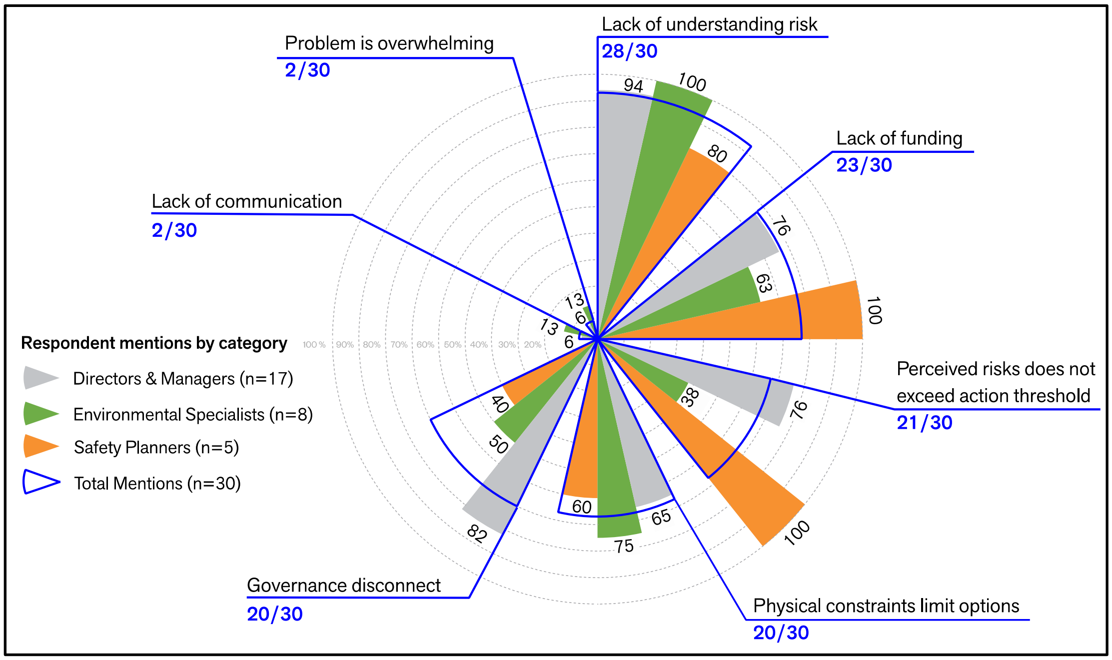
The following paragraphs present findings from this study, including barriers to adaptation, followed by the strategies that can help them overcome the identified barriers and concluding with recommendations to the U.S. Army Engineer Research and Development Center, and port decision-makers. By connecting the barriers to adaptation and the strategies needed to address them, this pilot study provides a framework to guide future port adaptation capacity-building actions.

Seven perceived barriers

This study identified and then measured consensus on seven perceived barriers to adaptation to climate and extreme weather (see figure on following page). It focused on three principle decision-maker types at medium- and high-use ports on the North Atlantic Coast: port directors, environmental specialists, and safety planners. Perceived barriers identified by this group include (1) the lack of understanding of the risks, (2) lack of funding, (3) perceived levels of risks do not exceed the action threshold, (4) governance disconnect, (5) physical constraints, (6) lack of communication amongst individuals, and (7) the problem (of adaptation) is overwhelming.

A higher percentage of port directors identified *lack of understanding* and *governance disconnect* in their responses about barriers; a higher percentage of the environmental specialists highlighted the *lack of understanding* and the *physical constraints of the ports* as barriers; and more safety planners mentioned the *lack of funding* and *perceived risks* do not exceed the action threshold as the barriers of concern (see figure on following page).

Seven barriers to climate and extreme weather adaptations resulted from 30 interviews in 15 North Atlantic ports. The value above each color is the percentage of respondents that mentioned that barrier within the decision-makers category (directors/managers, environmental specialists, safety planners). Blue numbers represent the total frequency of the responses (n = 30). Blue represents the overall percentage of responses for a barrier. (Graph credit: J. Menendez Lopez).

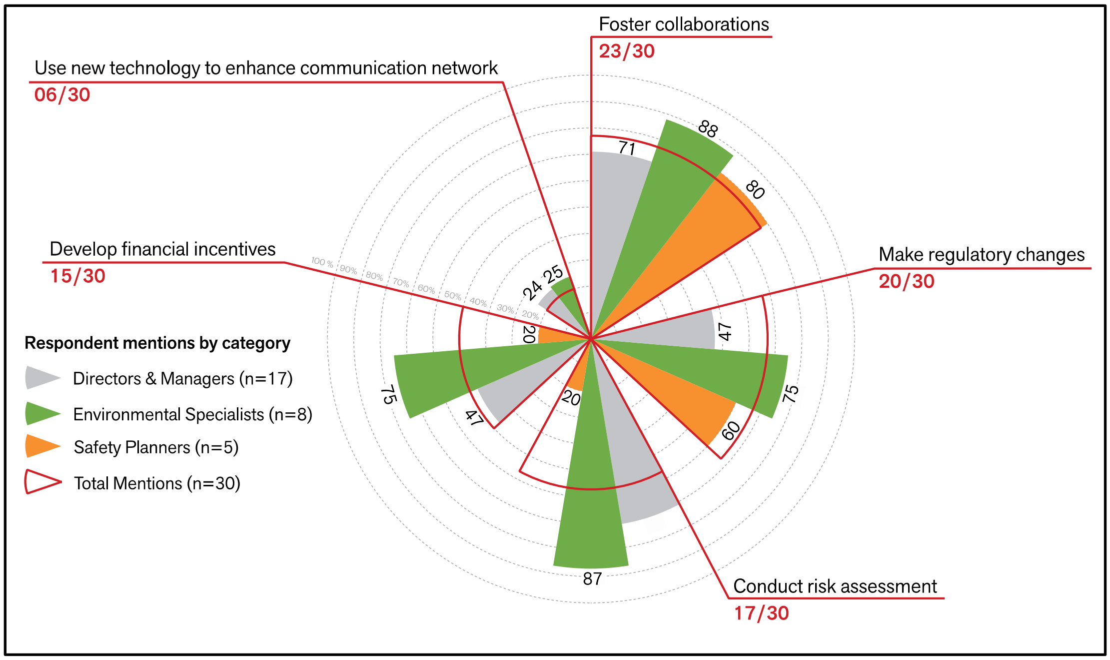


Five strategies to address barriers

The respondents also identified five strategies that could help them address the barriers to adaptation: (1) foster collaborations, (2) make regulatory changes, (3) conduct risk assessments, (4) develop financial incentives, and (5) use new technology to enhance communication network (see figure on following page).

A higher number of directors and environmental specialists highlighted the importance of fostering collaborations and making regulatory changes to encourage resilience planning. Safety planners agreed, and they highlighted the need to conduct risk assessments (see figure on following page).

Five strategies to overcome barriers to climate and extreme weather adaptations resulted from 30 interviews in 15 North Atlantic ports. The value above each color is the percentage of respondents that mentioned that strategy within the decision-makers category (directors/managers, environmental specialists, safety planners). Red numbers represent the total frequency of the responses (n = 30). Red represents the overall percentage of responses for a barrier. (Graph credit: J. Menendez Lopez).



Key recommendations

Addressing the barriers relies on private and public port entities to communicate and collaborate at the local, state, and national levels with institutions and agencies that have a vested interest in the ports. To address barriers to adaptation at the port level, this study recommends for USACE, policy makers, and other institutions do the following: (1) make regulatory changes to encourage resilience and provide financial incentives, (2) integrate risk assessment into the port management plan or conduct independent risk management assessment, (3) establish working groups and emergency response strategies for different natural hazards (flood barriers, etc.), and (4) enhance learning and data availability through collaborations (organizations, academics, government, etc.).

Directors and managers can play leadership roles in directing the environmental specialists and the safety planners to work together on risk assessment reports for the ports. The environmental specialists and the safety planners can promote the establishment of partnerships and collaborations that enable them to learn from ports that have more experience with storms, floods, or other natural hazards.

More work is needed to integrate a larger number of port stakeholders in the conversation, to make clear connections not only on what the barriers to adaptation are but also on who has the responsibility to remove them. Efforts should expand to understand risks at the port and their neighboring communities. The development of the approach and research methods used in this study can be used in other regions to measure consensus on barriers to adaptation and the strategies needed to overcome them.

1 Introduction

Coastal communities are experiencing worsening impacts from climate change-related natural hazards (Melillo et al. 2014). Although changes in the climate and extreme weather events are inevitable (Melillo et al. 2014; IPCC 2012), the magnitude of the damage to coastal areas and the critical infrastructure located there can be reduced through the implementation of climate and extreme weather adaptations (Füssel 2007). Seaports are critical infrastructure. At the national and global levels, trade and development rely on the efficient operation of maritime transportation[1]. To sustain these operations, it is vital that port decision-makers understand the risks and plan for potential impact. Because U.S. port resilience planning currently falls primarily upon port operators (Becker and Caldwell 2015), those equipped with knowledge about adaptation strategies can minimize their vulnerability to natural hazards (Nicholls et al. 2008).

Over a decade ago, the Intergovernmental Panel on Climate Change (IPCC) remarked that there were "research challenges in understanding the processes by which adaptation is occurring and will occur in the future"(IPCC 2007). Social scientists, in response, researched barriers to climate change adaptation and are developing theories to help understand them (Moser and Ekstrom 2010). Recent investigations stress that decision-making barriers slow the implementation of adaptation strategies (Moser and Ekstrom 2010; Biesbroek et al. 2011; Becker 2013). Such barriers include underestimating risk levels, lack of financing, lack of awareness, and misaligned incentives (Moser and Ekstrom 2010; Biesbroek et al. 2011).

This research builds on these theories of resilience barriers and ground truth findings from the indicator-based vulnerability assessment methodology developed for the 22 seaports that fall within the boundaries of the U.S. Army Corps of Engineers (USACE) North Atlantic Division (CENAD) (McIntosh et al. 2018). Through literature reviews, a compilation of databases, and an iterative, expert-driven process, a

[1] Asariotis, R., H. Benamara, and V. Mohos-Naray. 2017. *Port Industry Survey on Climate Change Impacts and Adaptation*. UNCTAD Research Paper No. 18. United Nations Conference on Trade and Development.

vulnerability indicator method that integrates 12 specific indicators was used for a comparative assessment of the vulnerability of the 22 ports in the North Atlantic (McIntosh et al. 2018). The indicators selected by the expert panel identified aspects of *exposure* and *sensitivity*, which are just two of the three components that comprise the concept of vulnerability (IPCC 2001). The final component, *adaptive capacity*, was not included in the index project, as no suitable indicators could be found for adaptive capacity. Hence, this research focuses on decision-makers' perceived barriers to adaptation for climate and extreme weather and considers adaptive capacity from the perspective of the perceived *needs* and *challenges* port decision-makers face when considering implementation of resilience investments. Specifically, what are the barriers preventing the integration of adaptive capacity to reduce the risk from climate and extreme weather events?

To identify seaport decision-makers' perceived barriers to climate and extreme weather adaptations, this project interviewed 30 port directors/managers, environmental specialists, and safety planners from 15 of the 22 medium- and high-use ports within the USACE North Atlantic Division (Figure 2). The remaining seven ports declined when invited to participate. This project focuses on ports but recognizes that barriers to adaptation also need to be considered in the context of a larger system. Through analysis of the interviews and a literature review on barriers and strategies to climate adaptation, a port-specific typology of barriers to climate and extreme weather adaptation was developed.

Following the Abstract and the Executive Summary of this report, Chapter 1 introduces the study, and Chapters 2 and 3 outline the objectives and the methods used to identify the key barriers to adaptation and the strategies to help port decision-makers overcome them. The report next describes the steps for the data analysis. Once the barriers were coded, a cultural consensus model (CCM) was used to identify and outline gaps and patterns of socially transmitted knowledge — the knowledge people use to interpret the world in making decisions that affect coastal cities and beyond (Romney et al. 1987).

The study also explored resources and strategies that the decision-makers identified as essential to helping them overcome the perceived barriers. Suggestions are offered on the role decision-makers could play to facilitate and implement the various strategies. Results for the different decision-maker categories are presented in Chapter 4. Chapter 5 discusses the barriers and the strategies to address them. The final section includes recommendations for resilience planning for port decision-makers, with the support of other agencies and organizations, and recommendations for future work (Chapter 6).

Additionally, to further ground truth aspects of the seaport vulnerability indicator methodology developed by (McIntosh et al. 2018), interview questions on how decision-makers perceive seaport vulnerability in the context of climate and extreme weather were included. In brief, the assessment finds that 80% of the 30 respondents explain port vulnerability in terms of only exposure and sensitivity — these are two of the vulnerability components, and only 30% talked about seaport vulnerability in terms of the third component, adaptive capacity. The responses by the directors and the environmental specialists followed the pattern mentioned above. However, safety planners explained vulnerability in terms of all three components, including adaptive capacity, more than the other decision-makers (80%, 4/5). More details are presented in Appendix A.

This research responds to the call to increase resilience and protect national critical infrastructure (Obama 2013) by assessing perceived barriers to extreme weather adaptation for ports. These study results can assist government agencies and port operators to understand and prepare for extreme weather events for the benefit of all who depend on a resilient maritime transportation system.

1.1 Barriers to climate and extreme weather adaptation

1.1.1 How are barriers defined?

The research in this study addresses barriers to adapt ports and port systems to the impacts of climate change, sea level rise (SLR), more frequent storms, increased storm intensity, and other extreme weather events. In 2007, the IPCC noted there were barriers that could impede implementation of climate change adaptation. At that time, *barrier* was defined as "any obstacle to reaching a potential that can be overcome by policies and measures," or as challenges that impede adaptation (IPCC 2007, Section 2.4.3). Barriers are often discussed in tandem with the term *opportunity* — "the application of technologies or policies to reduce costs and barriers, [to] find new potentials and increase existing ones" (IPCC

2007, Section 2.4.3.1). This potential for barriers and opportunities can vary across places and over time because they tend to be context specific (IPCC 2007).

In this study, barriers[1] are factors and conditions that impede, prevent, or delay processes for the development and implementation of climate change adaptation strategies for seaport systems (Biesbroek et al. 2011). In the literature, examples of these barriers include uncertainty, the cost of adaptation measures, fragmentation, rigidity, unawareness, lack of data, lack of national attention to climate change (Smith et al. 2009), as well as socio-cultural barriers and institutional barriers to action (Burch 2010). While research suggests that such barriers can be "overcome with concerted effort and creative management (Moser and Ekstrom 2010), there is no specific guidance for barriers that seaport decision-makers might face.

The challenge is that barriers "make adaptation efforts less efficient" and more difficult to achieve progress towards adaptation (Biesbroek et al. 2011; Huang 2012; Ekstrom and Moser 2014). As a result, some researchers have developed frameworks to diagnose barriers to climate change adaptation with a focus on planned adaptation (Moser and Ekstrom 2010). As the backdrop to identifying where barriers to adaption arise, they use an idealized stage for an adaptation planning process that includes (1) understanding the problem, (2) planning an option, and (3) managing or monitoring the effects of their actions. Ekstrom and Moser later tested the theoretical framework focusing on three potential sources of barriers: the actors (making decisions), the context (social, economic, or biophysical), and the system that is at risk of being impacted. Through these efforts, they found the most frequent barriers to be related to institutional governance and funding concerns. Additionally, these identified barriers were influenced by the attitudes, values, and motivations of the actors involved. Others agree that barriers are relative to a specific adaptive action, to the actor that can put them forward, and to the situation in which the action is taken (Eisenack and Stecker 2012; Moser and Ekstrom 2010).

[1] The definition of barriers and the main terminology used throughout this report can be found in Appendix E.

1.1.2 Some examples of barriers

In the academic literature on climate adaptation, the most frequently reported barriers relate to the institutional and social dimensions building resilience. Barriers can relate to how risk is understood in the context of planning for, managing, and implementing resilience strategies (Moser and Ekstrom 2010) or as a function of where they arise in the adaptation process (Biesbroek et al. 2013). Social barriers to adaptation relate to challenges in institutional governance (Ekstrom and Moser 2014) or the persistent problem of institutional fragmentation (Ekstrom and Moser 2014; Huitema et al. 2008), especially inside multi-entity organizations where different sectors need to interact and communicate to implement adaptation strategies. Other barriers are described as technical, for example when staff lacks the expertise or training to address a problem, or biophysical limitations, for example an absence of information on the biology or physical landscapes that leads to maladaptation (Moser and Ekstrom 2010).

Barriers can also be linked to specific planning actions and include scarce financial resources, limited training, conflicting timescales, governance fragmentation, the uncertainty of societal costs, or the future benefits of adaptations (Biesbroek et al. 2011). As an example, conflicting timescales happen when other issues have a more pressing nature and decision-makers are confronted with what to prioritize first. In general, the "traditional long-term planning [horizon] found in strategic policy documents (20 to 30 years) is preferred to having to plan for the long-term impacts of (an uncertain) climate change (100 years or more)"(Biesbroek et al. 2011). Lack, or inaccessibility, of resources can also be a significant barrier to climate adaptation (Füssel 2007), as many adaptation strategies are very expensive and have less-clear direct benefits.

In the context of decision-making, identifying barriers to climate change adaptations can be challenging due to factors such as the differences between the long-term impacts of climate change versus the short-term weather patterns; the need for better scientific models for predictions; and the inherent uncertainties of climate (Biesbroek et al. 2013).

In responding to what these barriers are, researchers also seek to explain society's ability to overcome barriers, and many studies categorize barriers to help determine where appropriate interventions can be targeted (Moser and Ekstrom 2010; Biesbroek et al. 2011; Biesbroek et al. 2013; Ekstrom and Moser 2014). In general, studies suggest that barriers to adaptation need to be understood in the context of society's ability to address them (Burton 2009; Adger et al. 2008), recognizing a latent adaptive capacity that is best explained as inaction (Biesbroek et al. 2013).

For ports, a number of barriers to climate adaptation have been evaluated (Becker and Caldwell 2015). These barriers include "organizational inconsistencies with regards to planning timeframes (5 - 15 years) compared with climate projections of 30 - 90 years"; then, there is the uncertainty of local climate projections that results in decision-makers delaying action until a later time — when there is perceived to be more certainty.

There will always be barriers to change, but barriers can be transformed. While a limitation is considered to be "absolute and unsurpassable," barriers are "mutable and surmountable" (Moser and Ekstrom 2010). To achieve successful adaptations, decision-makers need to not only understand the issues but also to increase their ability to navigate the labyrinth of barriers that emerge in the governance of adaptation (Adger and Barnett 2009; Adger et al. 2009; Moser and Ekstrom 2010)

1.2 Strategies to overcome the barriers to climate and extreme weather adaptations

Adaptation, as defined by the IPCC, means "any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2012). In this study, adaptation to climate and extreme weather is defined as actions decision-makers implement to respond to a predicted or projected natural hazard impact. These actions reduce the risk and increase the resilience of the port and are generally part of an ongoing process. Unfortunately, adaptation actions often take the form of reactive mitigation (after an event) rather than pro-active actions (before an event occurs). This adaptation strategy, though dominant (Measham et al. 2011), leaves coasts and communities vulnerable to future impacts (Measham et al. 2011; Burch 2010). For this reason, decision-making, adaptation strategies that overcome barriers can benefit from "leadership strategic thinking, resourcefulness, creativity, collaboration and effective communication" (Moser and Ekstrom 2011).

In 2011, the United Kingdom Climate Impact Program used a risk/vulnerability approach to understand climate adaptations. It integrated current-day vulnerabilities to extreme weather events with an assessment of future climatic risks and resulted in two adaptation categories (Scott et al. 2013). The first builds capacity for future changes through awareness raising, skill development, data collecting, monitoring and research, and the second implements adaptation initiatives such as technological, engineering changes, planning, design, legal/regulatory, insurance/financial measures, and management system change (UKCIP 2011).

States that have experienced disasters are already at the forefront of climate change policy. For example, in 2011, after severe storms and floods of 2010, the state of Rhode Island formed a state Climate Commission (RICCC 2012) and adopted an SLR policy for the state (in draft form at the time of the interviews) (CRMC 2009).

In 2012, researchers published work on “transformational adaptation” strategies (Kates et al. 2012). These are strategies that are much larger in scale and may transform a place or initiate a major shift in location (Kates et al. 2012).

Although in recent years the number of studies on adaptation in the context of climate has increased on scientific and policy agendas (Adger et al. 2007), numerous researchers have tried to explain the commonly observed “adaptation deficit”(Burton 2009) when needed adaptations are identified but their implementation is missing. The National Research Council notes that this deficit in adaptation is not only observed for developing countries but also in developed nations (NRC 2010).

1.3 Strategies for seaports

Seaports facilitate the exchange of goods and benefit for regional and national economies and social systems. Ports serve many different stakeholders and contribute to diverse goals that include “providing economic benefits, environmental protection, improving quality of life, reducing tax burdens, facilitating trade,” etc. (Winkelmans and Notteboom 2007). Therefore, when a natural disaster strikes a port, many stakeholders are affected directly and indirectly (Becker et al 2014).

In a recent study, surveyed port administrators around the world felt that adaptation measures should be taken into account when ports construct new infrastructure (Becker et al. 2011). Mississippi offers a recent example. After Hurricane Katrina destroyed the port of Gulfport, the port authority adopted a plan to elevate the entire infrastructure from 10 feet to 25 feet above mean sea level to enhance resilience to storms. In this case, $140 million was proposed to invest in structural resilience (Becker and Caldwell 2015). However, this strategy was never implemented, and funds originally allocated for the project were redirected to a channel dredging project so that the port could accommodate larger vessels.

Indeed, port adaptation measures can be a non-trivial investment of resources, and studies suggest that assessment of resilience strategies can benefit by understanding the needs of a wide range of stakeholders (Moser and Ekstrom 2010). One study, focused on coastal seaports, found that port operators, port tenants, and representatives from the public policy sector, academia, and community groups had a role to play in climate change adaptation (Becker et al. 2013a). Further, because natural disasters at ports can affect stakeholders directly and indirectly (Becker et al. 2014), a range of perceptions provides current (or historical) locally relevant data. Also, stakeholder's engagement and participation can lead to more effective adaptation (Wilbanks and Kates 1999; Eakin and Luers 2006).

For a coastal infrastructure, the ways in which these can adapt to the imminent risks of climate and extreme weather events are by protecting their infrastructure, by elevating their piers and facilities, by designing for submersion, or by abandoning the infrastructure (Becker et al. 2013) (Figure 1).

Figure 1. Four levels of port adaptation strategies: Protect, Elevate, Design for Submersion, and Abandon (Images: Protect, photo by **www.dutchwatersector.com**; Elevate, author unknown; Design for Submersion, Alabama State Port Authority; Abandon, Dan Cuellar 2012.)

At the policy level, to advance the adaptation of ports, policies could include the development of vulnerability assessment plans or incorporating resilience goals into the standard operations and management programs. Some ports could benefit from the acquisition of adjacent lands and properties or the acquisition of insurance coverage (Becker and Caldwell 2015). Becker and Caldwell (2015) found port stakeholder's strategies for resilience clustered into seven categories:

- Building codes and land use regulations
- Long-range planning
- Construction and design strategies (on and off port lands)
- Private sector and insurance policies
- Emergency preparations, response, and recovery
- Research
- Networks and new ways of thinking.

Ongoing, “todays needs and options” to address adaptation and resilience efforts “will depend on investments and decisions made in the past” (Crabbé and Robin 2006; Hallegatte 2009).

2 Research Objectives

This study collected data from 30 port decision-makers, representing 15 ports, on their perceptions of the barriers to climate and extreme weather adaptation and the strategies to help them overcome these barriers. It used a grounded theory approach (Glaser and Strauss 1967; Charmaz 2006) to develop the categorical classification for port-specific typology of adaptation barriers. This research also used a CCM (Caulkins and Hyatt 1999; Romney et al. 1987) to assess port decision-makers' level of agreement on climate and extreme weather impacts in the North Atlantic. It identified barriers to climate and extreme weather adaptation and assessed concepts of vulnerability as perceived by port decision-makers. Further, it defined knowledge and perception trends and gaps that local port authorities and policy makers can use to help in resilience planning and in developing extreme weather adaptation strategies for their ports.

The two main goals of this research are the following:

- Understand how port decision-makers perceive barriers to climate and extreme weather adaptation in the North Atlantic and how these perceptions relate to those identified in other studies on this topic
- Highlight decision-makers' perceptions of strategies that can help in overcoming these barriers

3 Research Activities and Methods

To assess port-specific barriers to adaptation to climate and extreme weather for the 15 ports within the CENAD, this project used a combined qualitative and quantitative approach to collect data:

1. Review literature on types and classification of barriers to climate and extreme weather adaptations.
2. Interview port decision-makers on their perceptions of the barriers[1] to adaptation and the strategies to address these.
3. Use a grounded theory approach to develop a typology of barriers to adaptation, and cluster barriers into categories.
4. Implement a CCM to measure consensus on barriers to adaptation.

In addition to describing a typology of barriers based on the decision-makers' responses and listing their responses on strategies to address these, this study considered how different decision-maker groups (directors/managers, environmental specialists, safety planners) perceive barriers differently.

3.1 Study location

This research uses 15 of the 22 medium-use and high-use ports (McIntosh et al. 2019) ports within the U.S.Army Corps of Engineers (USACE) North Atlantic Division[2] (CENAD), consistent with the sample population utilized for developing extreme weather and climate vulnerability indicators by McIntosh et al. (2019, Figure 2). The U.S. Army Engineer Research and Development Center is interested in piloting port resilience and vulnerability assessment methods with high-use ports[3]. By adding medium-use ports and restricting the selection to the North Atlantic

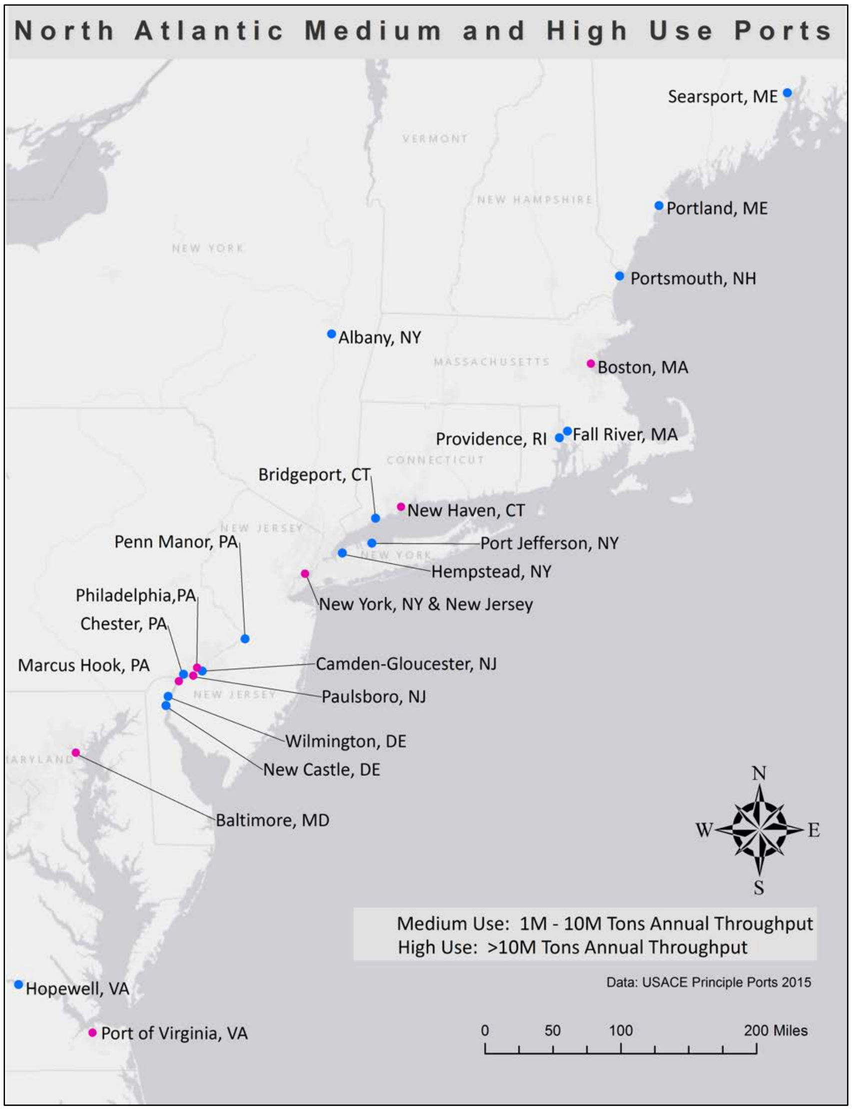
[1] Before the interviews, the interview protocol and procedures were approved by the Institute of Review Board (IRB) at the University of Rhode Island (IRB Approved 894694-8). This standard protocol required that interviewees be informed of the purpose of the study and that they give a written or oral consent to being interviewed and being recorded (for transcription purposes only). The majority of interviews (73%, 22/30) were conducted in person, 27% were conducted over the phone, 10 of the ports were visited.

[2] The North Atlantic Division is one of nine USACE divisions and encompasses the U.S. Eastern Seaboard from Virginia to Maine USACE. 2014. *USACE Civil Works Division Boundaries*. http://geoplatform.usace.army.mil/home/item.html?id=c3695249909c45a2b2e2c3993aff3edb. U.S. Army Corps of Engineers.

[3] Dr. Julie Rosati, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Personal communication, February 2015.

region, researchers could create a manageable sample of 22 ports. The proximity of these ports to the University of Rhode Island allowed for site visits and interviews.

Figure 2. The 22 medium-use (blue dots) and high-use (magenta dots) ports in the North Atlantic per 2015 USACE CENAD data.



3.2 Study participants

Many climate adaptation studies focus on stakeholders — those who can affect or be affected by achievement of an organization’s objectives (Freeman 1984). This study focuses on three types of stakeholders who have expertise and decision-making roles within the port: port directors/managers, safety planners, and environmental specialists. The responsibilities of each group are listed in Table 1.

Table 1. Description of responsibilities of decision-maker positions.

Position	Number Interviewed	Responsibilities
Directors or managers *Common titles* - executive director - director of operations - project manager	17	• Run port operations and systems (short- or long-term) • Perform maintenance of vessels and facilities • Supervise employees • Manage specific functions of port facilities • Plan efficient use of port resources, with attention to security, safety, and health of personnel
Environmental specialists *Common titles:* - marine environment and civil engineering consultant - manager of strategic planning - harbor master - environmental manager - project manager - climate mitigation and resilience manager	8	• Monitor related environmental regulations • Oversee environmental protection and other social responsibility functions.
Safety planners *Common titles* - vice president of sustainability (consultant) - chief harbor safety strategist and operations assistant	5	• Monitor and assess hazardous and unsafe situations • Develop guidelines for personnel safety

Interviewees mentioned their close collaborations with regional or state harbor masters and the U.S. Coast Guard (USCG) in preparing for natural hazard events or during emergency responses. In some cases, harbor masters are responsible for the safety planning of coastal infrastructure in a region. The position of the environmental specialist can often times be outsourced to private consultants. However, this study was limited to employees of the ports themselves.

Port directors/managers rely on communications with the environmental specialists, safety planners, or harbor masters and the USCG to stay informed on natural hazards and other climate and extreme weather events. Different ports — depending on who the decision-maker(s) communicate(s) with and the port director's/manager's prior experience with hazards — may respond differently to the same event. (When presenting results, references attributed to *directors* correspond to the directors/managers decision-maker type.)

Management and governance also vary across the ports. Those without a port authority are privately owned or managed by a private entity in the name of the state (Table 2). Also, the number of decision-makers and their years' experience can influence a port's response. These data are also included in Table 2.

Table 2. Demographics representing participating decision-makers.

Number of participating ports	15/22
Ports with port authority	9/15
Number of interviews	30
Types of decision-makers	
Directors and managers	17
Safety planners	8
Environmental specialists	5
Years of experience	
<5	7
5 - 10	7
11 - 20	8
> 20	8
Range of experience	1 - 46 (years)
Gender of decision-makers Female	8/30
Male	22/30

This study is exploratory; researchers were challenged to find willing respondents to represent the three categories of port directors, environmental specialists, and safety planners from 15 of the 22 of the medium- and high-use ports in the North Atlantic. Some port directors are charged with multiple functions and do not have staff with these specific titles.

3.3 Development of interview instrument: Semi-structured interviews

The research team developed open-ended questions to capture the perceptions of decision-makers in 22 medium- and high-use ports in the North Atlantic on barriers to adaptation and response strategies.

Additional questions explored the concept of *vulnerability* — to determine if interviewees understood the components of vulnerability (exposure, sensitivity, and adaptive capacity (McIntosh et al. 2019).

By coding the responses to these interviews, consensus on the perceived barriers to climate and extreme weather adaptation and recorded decision-makers' knowledge of strategies to respond were quantified. Additionally, the practices and circumstances that are locally relevant across the studied ports and the variation in the responses across the different decision-makers can be further analyzed and determined. The methodology and insights from this study can be applied to other areas/categories. The results and recommendations from this study can help address adaptation barriers so that seaports can respond to climate and extreme weather events.

This study addresses the need to quantify barriers first — as a precursor to drafting a strategic plan and recommendations to increase the port and the port community's ability to adapt to coastal hazards.

3.4 Overview of data collection

The data were collected over 4 months (November 2017 — February 2018). Decision-makers were identified using the ports' websites and direct phone calls. The identified decision-makers received information on the study, its goals and benefits (Appendix B), and a one-page project summary description (Appendix C) via email. Electronic communications were followed up with phone calls.

During the data collection period, 30 port decision-makers from 15 of the 22 ports were interviewed: 22 in person and 8 over the phone. Respondents answered questions about the barriers to adaptation (e.g., "What are some of the challenges to implementing extreme weather adaptation actions at your port?") and about the resources or strategies to help them overcome these (e.g., "What resources would enable you to overcome these challenges?") (Appendix D).

3.5 Data analysis methods

3.5.1 Coding of transcripts

A grounded theory (Glaser and Strauss 2017; Charmaz 2006) approach to identifying port barriers to climate and extreme weather events is an iterative process that allows for views and concepts to emerge and be grouped into unique themes or categories. After the transcription of the interviews, researchers coded the transcripts line-by-line. These were first coded for barriers, then for strategies, using the NVivo qualitative data analysis software package (NVivo 2014) . Reviewing the transcripts[1], researchers identified and classified barriers and strategies for overcoming the barriers independently and resolved differences where necessary[2] following the process laid out by Ekstrom and Moser (2014):

1. Each coder reviews interview transcripts and independently identifies the following:
   a. barriers to adaptation mentioned by respondents
   b. strategies mentioned by the decision-makers to overcome them.
2. Each coder develops a classification for each observation.
3. Coders compare the classifications and reconciles where necessary before coding all the interview transcripts and tallying codes. (This step adds rigor to the study). Main nodes and secondary nodes for coding (1) barriers and (2) strategies for overcoming the barriers were predetermined.
4. Discuss details regarding differences or similarities for the barriers mentioned across the three categories of decision-makers to answer if the barriers are seen differently.
5. *Frequency* is a measure of the number of times that a unique, clearly distinguishable barrier is mentioned. It is an indicator of the diversity of unique barriers within a larger class of barriers.
6. Regardless of how often the barrier was mentioned, frequency should not be interpreted as a direct indication of *importance* and cannot reveal how difficult it is to overcome a barrier.
7. Barriers and strategies will be coded and grouped by decision-maker type (managers/directors, safety planners, environmental specialist) for further analysis.

[1] Before the interviews, the interview protocol and procedures were approved by the University of California-Berkeley Human Subjects Committee. The protocol required that interviewees be informed of the purpose of the study and give written consent to being interviewed and being taped (for transcription purposes only). Almost all interviews (98 percent) were conducted in person, either at the informant's office or in a mutually agreeable location. The remainder was undertaken by phone due to scheduling constraints or the preference of the interviewee. IRB Approved 894694-8

[2] NVivo Coding comparison between coders; in the initial coding phase, yielded a 0.696 Kappa value (values between 0.40 - 0.75 = fair to good agreement).

3.5.2 Organization of results

The output of the cultural consensus model is presented first. Next are the identified seven major categories of identified barriers to adaptation (Figure 3). Each barrier is described and explained, and its sub-categories are presented and exemplified within the context of the decision-makers' responses. Next, the strategies to overcome the barriers to adaptation are presented. These clustered into five major categories of strategies. Each strategy is described, and its corresponding sub-categories are explained, with examples from port decision-makers.

3.5.3 Use of Cultural Consensus Model (CCM)

The CCM assumes there is a shared cultural knowledge or a cultural normative belief in a group. The use of the CCM guides the aggregation of individual "culturally correct responses" and measures the level of agreement between individuals (Weller 2007; Romney et al. 1987). A Pearson correlation coefficient measures the agreement to analyze the number of subjects and their frequencies.

The use of the CCM guides the aggregation of individual responses to a series of questions to an estimate of "*cultural correct responses,*" measuring the level of competence between individuals as well (Weller 2007). The CCM distinguishes patterns of socially transmitted knowledge people use to interpret the world to make decisions (Romney et al. 1987). This can be useful in decision-making for climate and extreme weather resilience investments.

For example, in a study on "cultural cognition of risk" that looks at climate change and the use of nuclear energy, researchers identified where members of the public disagreed on scientific facts surrounding risk (Kahan et al. 2011). Others have used it to analyze levels of competence among a group of people (Boster 1989).

The CCM is useful in assessing qualitative data that can be organized into categories. Researchers can use it to identify barriers and make recommendations for locally relevant constructive interventions to the extreme weather adaptation process.

4 Results and Discussion

In the beginning of this research, two main questions were posed: “What are some of the challenges to implement extreme weather adaptation?” and “What resources [or strategies] would enable you to overcome these challenges?” After interviewing 30 port decision-makers at 15 different ports in the North Atlantic region, the responses to these questions resulted in seven major barriers and five major strategies. The frequency of responses from each decision-makers group for each category of barriers and strategies is identified in Figures 3 and 5. A total of 17 port directors, 8 environmental specialists and 5 safety planners participated. Example quotations and references from the interviews are presented for the barriers and for the strategies to overcome the barriers[1]. This section presents the results of the CCM and then explains each identified barrier and the context in which it is mentioned (sub-categories).

4.1 A CCM to identify decision-makers’ adaptation barriers

First, respondents’ responses were coded to identify the major barriers as perceived by respondents. With barriers identified, the CCM analysis was used with ANTHROPAC 6.46 software (Borgatti 1996) to assess agreement between different respondents. The CCM measures the ratio of the variability in the data in the first to second factor loading[2] (>3.0). From the CCM, the respondents’ consensus measures (Table 2) and estimates of their competence or agreement with the group were derived (Appendix F). This analysis allows the identification of how subgroups (i.e., port directors, environmental specialists, safety planners) have common perceptions around barriers.

With a factor ratio of 3 (i.e., rounding of 2.91), the respondents are said to be drawn from a single population, meaning that there is agreement in their responses on the barriers to adaptation. A smaller factor ratio would indicate that respondents pertain to two or more populations — meaning

[1] Some quotations from the interviews have been lightly edited and condensed for clarity purposes. Verbatim quotations are on file with the researchers.

[2] The factor loadings are based on the common variance between the analyzed responses. Each decision-maker’s response is compared to the responses from all the decision-makers (n = 30). This process generates a correlation matrix where each column of squared loading factors (e.g., eigenvalues) represents the amount of variance accounted for by a factor {NCSU 2018}. Therefore, factor loading one accounts for the variability in the data, and each succeeding factor loading accounts for as much of the remaining variability.

that their views (on climate and extreme weather) are not homogeneous — having different perceptions of what the barriers to adaptations are. The competence score represents a measure of their shared knowledge. For the studied group, the average competence score is 0.598, and the values range from 0.981 (highest agreement) to 0.067 (low or absence of agreement) (Table 3). As an example, when two respondents answered that barrier #1 and barrier #2 were the main challenges, their competence score could be closer to 1, or 0.981. However, when a third respondent mentioned barrier #3 to be most important, its competence score could be closer to 0.598. The full output of the competence model is presented in Appendix F.

Table 3. CCM analysis: consensus for 30 port decision-makers on the perceived barriers to climate and extreme weather adaptation. Factor loading one accounts for the variability in the data; factor loading two accounts for the remaining variability.

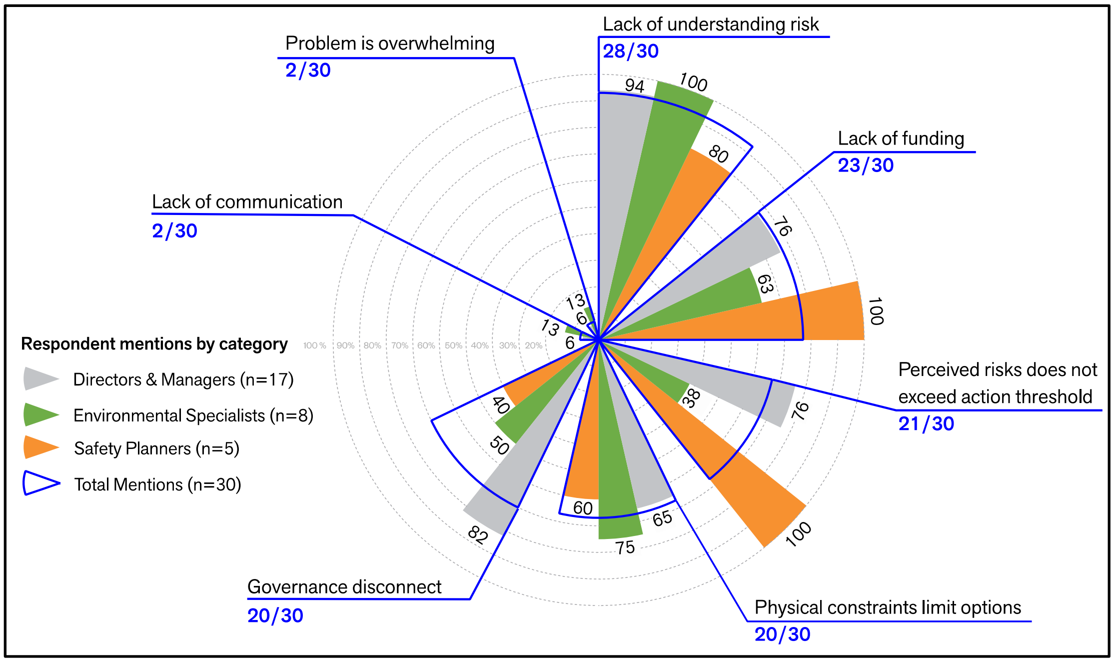
	1st Factor	2nd Factor	1st to 2nd Factor Ratio	Average "Competency"
Sample (n = 30)	14.282	4.905	2.912	0.598 (St. Dev. 0.25)

By measuring consensus in decision-makers' responses to the barriers to adaptation, it is possible to identify the knowledge people use to interpret the world when making decisions (Romney et al. 1987). Climate change studies stress how decision-making barriers can slow the development and implementation of adaptation strategies (Moser and Ekstrom 2010; Biesbroek et al. 2011). The measurements of the cultural consensus model provide a signal of the high level of agreement shared by port decision-makers — an agreement that could facilitate conversations and collaborations to build port resilience in the North Atlantic region. The strength of the results on the barriers comes from having found consensus among the respondents (Table 3, Figure 3). These results can guide plans and strategies to overcome the barriers.

4.2 Typology of port barriers to adaptation

This analysis revealed seven major categories of perceived barriers to climate and extreme weather adaptation, as perceived by 30 port decision-makers in 15 of the 22 medium- and high-use ports in the North Atlantic. Figure 3 shows the number of respondents that mentioned at least one barrier from each of the seven categories at least one time during the interview.

Figure 3. Seven barriers to climate and extreme weather adaptations resulted from 30 interviews in 15 North Atlantic ports. The value above each color is the percentage of respondents who mentioned that barrier within the decision-maker type (Directors/Managers, Environmental Specialists, Safety Planners). Blue numbers are the total frequency of the responses (n = 30). Blue-outlined sections are the overall percentage of responses for a barrier (Graph credit: J. Menendez Lopez).



The following section describes the seven categories of barriers. Each has sub-categories, setting the context in which the barrier was mentioned. For example, the category *lack of understanding of risks* has six sub-categories. One is *confusion over the level of risk,* and another is *the difficulty of predicting where impacts will be*. Under the sub-category *responses by decision-maker type*, some distinct responses and differences in viewpoints of given groups were highlighted. In parenthesis the coded number and type for the respondent are noted, as follows: DIR = port director, ES = Environmental specialist, SP = Safety planner. The number following the respondent type is the participant's number; thus, DIR18 is a port director coded as #18. When decision-makers' responses to barriers differed, specific examples are provided.

While a higher number of port directors identified *lack of understanding* and *governance disconnect* in their responses about barriers, environmental specialists mentioned *physical constraints of the ports* second to the *lack of understanding*. For the safety planners — those who deal with port safety daily — mentioned *the lack of funding* as frequently as *the risks do not meet an action threshold* as their top-two barriers (Figure 3).

4.2.1 Barrier 1 – Lack of understanding of risks

4.2.1.1 Description of Barrier 1

The lack of understanding of risks was mentioned by 28/30 respondents (Figure 3). This is further explained by the barrier's sub-categories (Table 4) which include (1) Confusion over the level of risk, (2) Difficulty of predicting where the impact will be, (3) Lack of awareness of risk, (4) Lack of experience with extreme events, (5) Political discord, and (6) Lack of understanding of unintended consequences. This is a barrier that typically arises at the beginning of a planning process (Moser and Ekstrom 2010). Understanding that adaptation is a process is key to having rational decision-making that accounts for understanding the problem, planning adaptation actions, as well as managing the implementation of their strategic options (Moser and Ekstrom 2010).

Within the IPCC, addressing uncertainty for decision-makers has surfaced as an important topic. Social scientists look at adaptation barriers regarding people's willingness to act, or their motives and willingness to act, in the context of decision-making processes (Tompkins et al. 2010; Biesbroek et al. 2011). These studies find that social factors like attitudes, values, and ethical beliefs explain how individuals chose to engage in the adaptation process. Therefore, these social factors present a constraint that defines people's adaptive behavior (Biesbroek et al. 2011).

In Table 4, the levels of agreement between the decision-maker categories are color-coded to denote high agreement to low agreement, as found by the CCM.

Table 4. Lack of understanding of risks, and its six sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Lack of Understanding Risks (93%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Confusion over the level of risk	18	25	20
Difficulty of predicting where the impact will be	35	63	60
Lack of awareness of risk	29	38	20
Lack of experience with extreme events	59	38	60
Political discord			20
Lack of understanding of unintended consequences	47	63	40

High agreement
Moderate agreement
Low agreement
Not mentioned

Most sub-category barriers relate to the difficulty in predicting impacts or if the hazard will occur (Table 4). Many decision-makers felt that severe weather events in the past (if any) did not predict the future, ". . . The storm was over 50miles/hours gusts, but we typically dont see a whole lot of these [level of the storm], and there certainly could be a lot of damage to the buildings and all the structures . . ." (DIR18)

The respondents also mentioned the difficulty of predicting where the flooding will be. What is expected to happen may not happen, and what does happen may demand a different response. In the words of one decision-maker: ". . . the flooding was coming from the *other* way . . . it was coming from a direction people were *not* expecting it . . ." (ES29)

Respondents described resilience planning as often reactionary and myopic, with ports engaging in mitigation planning only after a natural hazard and then preparing to respond to similar hazards in the future based on the latest experience, rather than to the other plausible events. As one decision-maker said, "I think that we have done enough . . . to measure ourselves up against the next Hurricane Sandy . . . But unfortunately, the reality is Sandy was not nearly as bad as it could have been." (DIR23)

Environmental specialists emphasized the need to conduct regular risk assessments. One said, "Even if our terminals are resilient, getting goods and services off the terminal and over the transportation network might pose challenges if . . . networks are not adequately resilient." (ES10)

Unintended consequences are defined as post-hazards effects that were not anticipated. One safety expert's statement reflected what others had similarly expressed, ". . . because we got hit with flooding and surge, we . . . react to flooding and surge . . . there is not really a focus on the other hazards we are facing." (SP21)

4.2.1.2 Responses by decision-maker type

Of the five safety planners, four mentioned this barrier. They were the only ones to cite the lack of understanding of risk in the context of political discord (Table 4). In the minds of these individuals, the priorities among politicians are narrow and not necessarily in alignment with climate adaptation. As one safety officer explained it, "Because of the politics, actions tend to be a little myopic." (SP21)

Although advances in science and new scientific models can assist decision-makers in the understanding of complex problems, the ambiguity and inherent uncertainty of long-term climate change impacts challenges the short-term dynamics of the politics in decision-making (Biesbroek et al. 2013). Respondents in this study felt the difficulty of predicting what impacts will take place or if a hazard will occur in the future. For them, better scientific models for predictions of natural hazards are needed to better understand the inherent uncertainties of climate. In some cases, respondents cannot recall when the last natural hazard affected them (Moser and Ekstrom 2010), reducing the urgency to understand and plan for long-term extreme weather impacts. Hence, understanding the differences between the long-term impacts of climate change and the short-term (societal) dynamics makes adaptation planning even more difficult (Biesbroek et al. 2013).

4.2.2 Barrier 2 – Lack of funding

4.2.2.1 Description of Barrier 2

Lack of funding was mentioned by 23/30 respondents (Table 5). This barrier is defined as the absence of financial resources or the absence of trained human resources to implement the needed adaptations. There are three sub-categories within this barrier: (1) Cost of adaptation, (2) Environmental regulations increase costs, and (3) Lack of funding (in general terms[1]) (Table 5). Lack of funding is a dominant obstacle. Presently, increasing the robustness of infrastructure to withstand more frequent extreme events is often delayed due to the lack of financial resources (Eisenack et al. 2014).

Table 5. Lack of funding and its three sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Lack of funding (77%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Cost of adaptation	24	38	60
Environmental regulations increase costs	6		
Lack of funding (in general terms)	59	50	100

Port facilities across the United States have old, aging infrastructures that need ongoing maintenance. Maintenance can be seen as an opportunity to make improvements that integrate resilience to climate and extreme weather considerations. However, planning for smarter, long-term investments in resilience adds to the costs of adaptations.

One director said, “We inherited some old facilities at the port. We are . . . rehabilitating our main pier . . . built in 1956 . . . [and] beginning to deteriorate . . .” But, as the words of another director made clear, the barrier to adaptation “. . . comes down to money.” (DIR25)

[1] Sub-categories that include ‘in general terms’ are designated to cluster responses that did not fit in the other named sub-categories. This was done to avoid creating many distinct sub-categories with only one sample reference.

This barrier also related to the need for a *change in the [port] agency's culture* as well as the time investment to plan ahead. Too often, ports ". . . do not have a planning staff that deals with environmental issues." (DIR7)

Decision-makers talked about this barrier as it relates to municipal government's limited funds and the complexity of retrofitting a port. Often, state projects do not meet requirements for federal support, which may favor regional or interstate projects. As one director explained, "If I were going to build a new bridge that connects two states, that would get money. If I am looking to elevate a bridge in my state, that probably would not . . ." (DIR5). This is all the while ". . . municipal governments [funding] have been trimmed down to the bottom." (ES30)

This barrier was of concern in the context of the need and cost of adaptation versus the need for and cost of regular maintenance as ". . . to implement adaptations, everything is very expensive . . . over a million dollars." (SP21)

For old ports and their infrastructure, there is the additional challenge of keeping up with today's larger ships and their ability to respond timely to an imminent weather event. Safety officers explained that while ships are getting bigger, many old ports' waterways are narrow. In a significant weather event, the captain of the port or the USCG may direct the port's ships out to sea, but because of the narrow turning basin, ". . . we [captains of some large ships] may not be able to follow those directions." (SP16)

4.2.2.2 Responses by decision-maker type

Lack of funding was the second barrier most mentioned by the decision-makers — 13 directors, 5 environmental specialists, and 5 safety officers. In Table 5, the levels of agreement are represented by their percentages; these are the number of mentions per decision-maker category.

Regarding the lack of funding barrier, directors were clear in their concerns about other sectors that rely on ports and waterways and that are already challenged by limited funding, ". . . the commercial fishing industry, with all the regulatory problems that they have, cant bear the financial burden." (DIR14)

Respondents spoke of how environmental regulation such as compliance with the American Disabilities Act (ADA) can increase the costs of the needed adaptation, which "is extremely challenging [when space is limited]." (DIR5)

In this category of barriers, one environmental specialist mentioned the port's electrical components' exposure to climate and extreme weather events. This included the reference to newer technology not performing under extreme weather conditions. One environmental specialist noted the concern that "electrical substations are very low and not elevated sufficiently . . . they could be elevated, but it is a huge expense." (ES30)

In other studies, the lack of funding is explained in the context of a governance void (Hajer 2003), the absence of leadership (Kretsch 2016; Becker and Kretsch 2019)[1], and/or lack of will to invest (Barnett et al. 2013). However, ports need to keep their competitive edge — looking into the future, the investments of today depended on the investments of the past (Pechan 2014; Hallegatte 2009; Crabbé and Robin 2006). Port decision-makers need to understand that financial constraints can become more of a burden over time as they address shortages in budgets and other priorities (Ekstrom and Moser 2014).

4.2.3 Barrier 3 – Perceived risks do not exceed an action threshold

4.2.3.1 Description of Barrier 3

Perceived risks do not exceed an action threshold was mentioned as a barrier by 21/30 respondents (Figure 3). Here, there is an awareness that a risk exists, but the risk has not exceeded a magnitude or intensity to prompt an action. These results are in agreement with Barnett et al. (2013) and link to lack of understanding (barrier #1) as it relates to absence of will to invest in the unknown (Barnett et al. 2013). These responses not only highlight the importance of having information to better understand the risks — prior to an investment but also the importance of having an informed governance.

This barrier is related to barrier two (a lack of understanding of the risks). Even when the risks are known, mitigating for them is not necessarily a priority. There were eight sub-categories in this perceived barrier (Table 6): (1) Perceived risks do not exceed action threshold (in general terms),

[1] Becker, A. 2014. *Port Cities Preparing for Changing Oceans*. Presentation delivered to the Consortium for Ocean Leadership Council – Public Forum on the Urban Ocean. Washington, DC.

(2) Agency culture is not forward thinking, (3) Climate denialism, (4) Conflicting priorities (e.g., going green versus resilience), (5) Lack of will to invest in the unknown, (6) Planning for future climate not necessary at present, (7) Resilience improvements impact business continuity, and (8) Resilience investments are not a priority.

This barrier was mentioned in the context of ports being unwilling to invest in the unknown. In the words of one environmental specialist, "It is a cost-benefit risk management decision to say how much are you willing to spend for an event that may — or may not ever — take place . . ." (ES22) Another spoke of the impact on work stream and revenue flow: ". . . it is hard to, say, raise a terminal by two feet without completely disrupting the flood of commerce over those terminals." (ES10)

The sub-category perceived risks do not exceed an action threshold speaks to the challenge of disruptions and how planning future reconstruction projects could affect the ability to keep up with operations, given a port operating at near capacity. Respondents who mentioned this barrier emphasized that the mission of terminals is to serve their customers, which means, ". . . get more product in and get it out of the gate." When "ports are locally own and operated, they do not [always] have the big global picture." (DIR7)

Although respondents indicated that there is a need for adaptation to natural hazard events, they suggested that priority still is given to other more immediate tasks related to standard operations, maintenance, and replacement of equipment. One director explained, "Taking the time and energy to create planning and think that far ahead . . . is a use of resources. That is time that could be spent doing something else like addressing paving concerns, or . . . working to improve labor circumstances or maintaining equipment." (DIR17)

4.2.3.2 Responses by decision-maker type

Thirteen directors, three environmental specialists, and five safety planners mentioned *Perceived risks do not exceed an action threshold* as a barrier. In Table 6, the levels of agreement are represented by their percentages; these are the number of mentions per decision-maker sub-category.

Table 6. Perceived risks do not exceed an action threshold, and its eight sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. The colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Perceived risks do not exceed an action threshold (70%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Perceived risks do not exceed an action threshold (in general terms)	12	13	20
Agency culture not forward thinking	6		40
Climate denialism	6		40
Conflicting priorities (going green vs resilience)	6	13	
Lack of will to invest in the unknown	6	13	40
Planning for future climate not necessary at present	29		
Resilience improvements impact business continuity	18	13	
Resilience investments are not a priority	35		60

All safety planners felt this was a barrier (almost double the response percentage of the other two groups of decision-makers). Safety planners mentioned it in the context of decision-makers lacking the will to invest in the unknown and in the difficulty of predicting the future). Such investment is especially difficult for ports that have little or no experience with severe storms or flooding events. “We need to change the culture and start to think . . . forward . . . get in the right mindset of ‘this is . . . real’ . . . we need to face it.” (SP21)

Another safety expert explained the dilemma of requesting $100,000 to raise his port’s substation because of SLR, being asked to justify that expenditure, and getting the response, “Why would I spend money on something that is predicted versus something that I know that right now needs to be done?” (SP13)

Environmental specialists mentioned the conflict between green investments and adaptation investments:

> “There are consequences of going green. A number of the terminals, particularly with their equipment, have moved from diesel equipment to electric equipment. So now, all the sudden you got electric motors that are inundated with water . . . in the

> past, if they were diesel or motor engines the impact would have not been as great. Going green has had an impact on your resiliency to stormwater damage." (ES22)

Directors and safety officers perceive that agency culture is not forward thinking; some of their ideas align with climate denialism: "I am not convinced that there is climate change" (DIR14), or in mentioning that the science is not solid and that there are too many contradictions, in the opinion of a safety planner, "You know, weather fluctuates! I am trained to look at facts and in some cases statistics and evidence." (SAF16)

4.2.4 Barrier 4 – Physical constraints limit adaptation options

4.2.4.1 Description of Barrier 4

Twenty of 30 respondents mentioned physical constraints limit options as a barrier (Figure 3). This is a location-specific factor or a physical/geographical-specific characteristic that limits the options for the port's infrastructure adaptation. There were four sub-categories of this barrier (Table 7): (1) The complexity of refitting for resilience, (2) Existing facilities under-designed for present and future conditions, (3) Lack of practical solutions, and (4) Port is restricted to its current location (it cannot move).

Most decision-makers are aware that the growth and development of ports, parallel to coastal development, and the expansion of other sectors reduce the area that would be needed for climate and extreme weather adaptations. Aging of the infrastructure, geophysical changes of the coastal landscapes, and other regulation conditions add to the complexity of this barrier. These facilities are presently under designed for present day and future conditions. Other studies explain this physical barrier noting that because of their placement and their geographical location, ports are constrained (Adger et al. 2009).

One director said, "We inherited old facilities. The port was built in 1956, the pier is beginning to deteriorate on the outer shore side . . ." causing sinkholes on the deck. (DIR1).

Table 7. Physical constraints limits options and its four sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

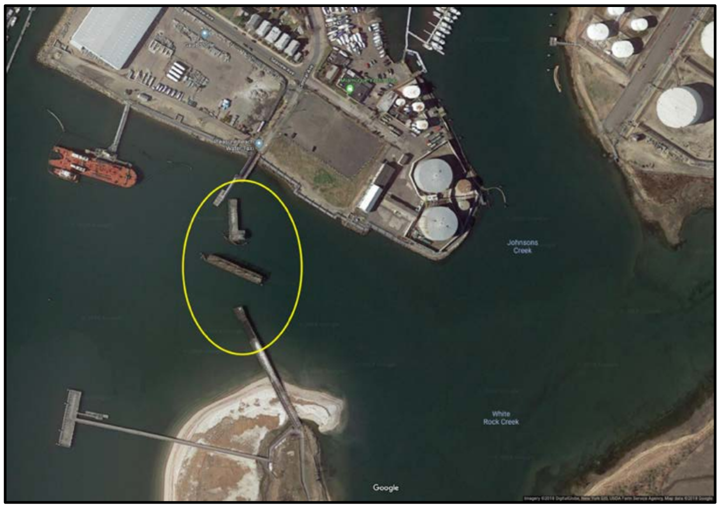
Physical constraints limit options (67%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Complexity of refitting for resilience	24	50	
Existing facilities under-designed for present and future conditions	77	25	20
Lack of practical solutions	18	25	20
Port is restricted to its current location (it can't move)	29	13	

Another, referring specifically to container terminals, explained, ". . . any study is going to [say] that in order to raise the berths, you . . . have to have an additional strengthening of the structure itself . . ." (ES22). Another said, "A lot of the infrastructure drainage and so forth . . . wasnt really originally designed to accommodate what we are seeing and what we will see in the future." (ES29)

Respondents also offered reasons why expansion into other nearby areas often is not possible — simply because of how a coastline is developed. One director explained that you might think it easy to identify areas along those rivers, clear them, and make them available for water to flow, but he said, "Unfortunately, they are all commercially occupied now." (DIR7)

Retrofitting for resilience becomes even more complex when coupled with ADA and other regulations. One director said, "How can we do port adaptation planning and remain compliant with ADA as well? Because of the transition, the free-board between the vessel and the dock, you have to accommodate a 20-foot transition for ADA: that is extremely challenging" (DIR5). Another respondent mentioned the inability to address navigational hazards such as an old, decommissioned bridge in a New England waterway for which there was no money for deconstruction (Figure 4).

Figure 4. Without funding for deconstruction, a decommissioned bridge becomes a navigational hazard. (Google Earth image).



4.2.4.2 Responses by decision-maker type

Fourteen directors, four environmental specialists, and two safety planners mentioned that their port's physical constraints limit options as a barrier to adaptation (Figure 3).

The directors and the environmental specialists explained this barrier in similar terms (Table 7). Refitting ports is a challenge and an opportunity. It is complex and difficult because of the extensive yard areas that would need to be elevated and the need for continuous investment. One environmental specialist noted, ". . . every time you invest, it is an opportunity to give it [the port/port infrastructure] more lifespan." (ES30). "The port could be elevated as we rebuild . . . [but] there is a lot of things in a container terminal that you also have to do at the same time when you do that. The barrier is the physical constraints, but there are also opportunities." (ES2)

Safety planners mentioned this barrier in the context that the current facilities are under designed and practical solutions are lacking (Table 7). "Right here [around the port authority headquarters], the challenge is to keep the water from coming up into the side. So, if you had that wall in place but there is precipitation, instead of surge, now you are trapping the water in" (SP21). As mentioned earlier, another safety officer explained the difficulty of today's large ships to turn around within the narrow space of some older ports' waterways, especially amid a serious weather event. (SP16)

4.2.5 Barrier 5 – Governance disconnects

4.2.5.1 Description of Barrier 5

Governance disconnect was mentioned by 20/30 respondents (Figure 3). There are seven sub-categories within this barrier (Table 8): (1) Complexity of multi-entity planning, (2) Disincentives for resilience investment (Federal Emergency Management Agency [FEMA][1]), (3) Lack of clarity over who should pay for resilience, (4) Lack of clarity over who will maintain or control resilience infrastructure, (5) Lack of direction from above, (6) Political pressure, and (7) Seaports are not prioritized in large-scale regional planning.

Table 8. Governance disconnect and its seven sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Governance disconnect (67%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Complexity of multi-entity planning	47	63	
Disincentives for resilience investment (FEMA)	6	13	
Lack of clarity over who should pay for resilience	12	13	20
Lack of clarity over who will maintain or control resilience infrastructure	35	13	20
Lack of direction from above	29	50	20
Political pressure	6	13	40
Seaports are not prioritized in large scale regional planning	24	13	40

Nine of the 15 participating ports in the study had a municipal or regional port authority. The remaining six were either privately owned or had an agency acting as a corporate trust on behalf of the port owners. Governance disconnect relates to the complexity of planning within a multi-entity organization. This leads to a lack of clarity on who decides on infrastructure resilience and who controls the investments.

"We recognize extreme weather conditions, but most of the port is privately owned." (DIR5). Another director said, "We are not a port

[1] This challenge regards the FEMA reconstruction regulations.

authority, we are a corporation, so we are expected to stand on our own throughout. We are dependent on the state for our capital expenditures like [the] two new gantry cranes we just received." (DIR24)

Environmental specialists and safety planners agreed. "There are multiple terminals that operate within the port that are private." (ES12). "Who is going to pay for adaptations? . . . to control it? . . . to maintain it?" (SP21)

Directors also spoke of the challenges of being a multi-entity organization where facilities and terminals under the port's authority had different landlords and different management frameworks. Respondents often described the administration of ports as being fragmented. "Long-term raising of the land would be extremely challenging with how fragmented everything is down here." (DIR3). Another said that while having a good relationship with the private owners of the facility, he wasn't always aware of their plans. "I am not aware of … a climate adaptation plan." (DIR14). There was also mention of how governance differs port to port. In one director's port, his team had little or nothing to do with terminal operations. "We are here basically just to help with regulatory issues and try to access resources for infrastructure improvements." (DIR7)

Collaborations with other agencies were also challenged by whatever was the focus and priorities of those agencies at a given time. For example, respondents stated that post disaster, FEMA only compensates for the costs of bringing the port back up to the required basic standard code. This gives ports little incentive to elevate their infrastructure beyond the minimum required, as some respondents mentioned:

> FEMA will give you a reimbursement to put a set of offices (like an office trailer) back where it was, and you dont have to elevate it. The code may require you to elevate, but FEMA doesnt necessarily give you any additional compensation beyond what the basic code requirement is. They will give you additional funding [to meet the basic code] if you say, 'I want to elevate it and I have a set of standards that predicate that I elevate.' (DIR23)
>
> From a restoration, resiliency issue, the prioritization of being able to get trade up and operating so that you can open the airport, you can open the seaports, you can get relief materials so that you can

> get equipment in to start the cleanup—that, from a policy perspective, has got to change as well. (ES22)

One environmental specialist spoke of this port's seawall damage in a previous storm, and because much of the cost of the repairs were made with FEMA money, the new seawall "could not be rebuilt any higher or different than what it was when originally constructed." (ES30)

This barrier was often mentioned in the context of lack of direction from above. "I think that as the port operators, we are probably not looking to make those investments." Asked if the port has a management plan that considers climate and extreme weather resilience, this environmental specialist said he was not aware of one. "We haven't been asked to develop one; so, I don't think that they have one specific for natural hazards." (ES2)

4.2.5.2 Responses by decision-maker type

A total of 11 port directors, 6 environmental specialists, and 3 safety planners mentioned governance disconnect being a barrier (Figure 3). For directors, this barrier is second in ranking after the lack of understanding of the risk.

In the subcategories, directors and environmental specialists saw the complexity of multi-entity planning as a factor.

There is high agreement throughout most of the sub-categories. However, safety planners did not mention multi-entity planning or the disincentives of FEMA regulations as a concern. Rather, they highlighted the barrier as driven by political decisions, ". . . we got to play politics to get the finances." (SP26), or they believed a cause was a lack of direction from above or the result of ports not being prioritized in large-scale regional planning. "We depleted that money from the Department of Defense to put it into different programs and now . . . we are flying 50-year-old planes. So, all [decision on where they will direct the money] is on who decides to pull the strings at any given time." (SP16).

Governance disconnect affects adaptation efforts at many levels. Others describe this disconnect in the context of institutional crowdedness and institutional void, or in the context of institutional fragmentation (Ekstrom and Moser 2014); it is also described as governance fragmentation (Biesbroek 2011), and institutional governance challenges (Ekstrom and Moser 2014). This barrier is not singular to climate and extreme weather adaptation situations but present generally in all types of governance dealing with a complex problem (Eisenack et al. 2014).

Decision-makers can be informed of many positive benefits and social-economic outcomes of implementing needed adaptations, but their governance will still be constrained by short-term budgetary cycles (Burch 2010) or outdated constructions standards. Respondents mentioned this limitation: governance disconnect arises when collaborating with other agencies. FEMA might favor investment on preparation, response, and recovery for disaster (FEMA 2015) and provide less funding for mitigation activities (Becker and Caldwell 2015). As an example, after experiencing a storm or a natural hazard, mitigation was directed towards increasing the port's resilience to a similar experienced event. The port could only get Federal funding to rebuild to the pre-disaster standard or rebuild with some improvements that integrated updated SLR building codes (FEMA 2015). However, *if* ports had more funding, they would opt to maximize the investment by building above the FEMA standards, integrating newer SLR projections to extend the lifetime of the investment.

Similar to what respondents described as a lack of direction, this barrier is mentioned in the literature in the context of the lack of clarity of responsibilities for adaptation at local levels (Ekstrom and Moser 2014; Huitema et al. 2008; Mukheibir et al. 2013), It can be a political — because of costs. In some cases, an elected official will defer adaptation because of the high costs (Vine 2012). Furthermore, governance disconnect is linked to the absence of leadership and the need for timely decision-making routines (Burch 2010) when dealing with a system of concern (Moser and Ekstrom 2010)

4.2.6 Barrier 6 – Lack of communication amongst individuals

Lack of communication amongst individuals was mentioned by only 2/30 respondents (Figure 3). It was mentioned by one director (6%) and one environmental specialist (13%). In general terms, this barrier relates to keeping staff and stakeholders informed of changes in climate and weather events, as well as adaptation strategies, to be prepared and able to sustain port operations. The director noted, "Communication is always the key, making sure that our staff is informed about our plans moving forward to adapt to the changing weather patterns, communicating with the captains of the vessels." (DIR1). The environmental specialist saw recent improvements in communications but added, "But, that [communications] can definitely be an issue from time to time." (ES12)

Biesbroek et al. (2011) also identified lack of awareness and communication as a barrier to climate change adaptations. Lack of awareness, or media misinformation, negatively influenced needed public and government support for climate adaptation (Biesbroek et al. 2011). As an example, news regarding errors in the IPCC report, in 2013, negatively influenced opinions surrounding climate change (Leiserowitz et al. 2013) generating skepticisms and mistrust. Communication, between science, policy, and the public, is vital to increasing general awareness about potential impacts of climate change (Moser 2010; Biesbroek et al. 2011).

4.2.7 Barrier 7 – The problem is overwhelming

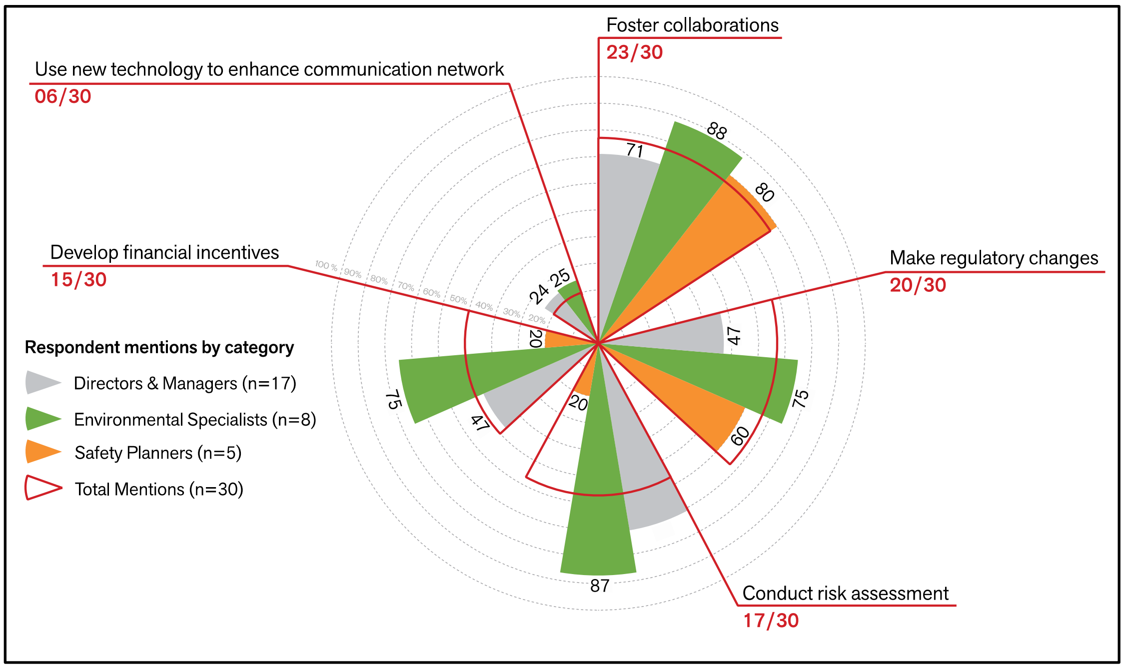
The problem is overwhelming was also mentioned by only 2/30 respondents (Figure 3): one director (6%) and one environmental specialist (13%). This barrier relates to the enormity of the climate change problem and humans' inability to reverse course on global warming. It also relates to the realization that regardless how much the port prepares, it will always be vulnerable. "The electrical component is of concern, we have substations that are very low elevated. There are two major sub stations for this area that are below 15 feet in elevation. Now, they could be hardened, they could be elevated, but it is a huge expense. . . I think that the electrical grid is a concern" (ES30).

> … you cannot control mother nature, the severity of it. For a hurricane to come through, there is only so much you can do. You are never going to come out of it unscathed. So, obviously, there are challenges with all that. Although you can prepare, . . . you are always vulnerable at some of these extreme weather changes. (DIR25)

4.3 Strategies to overcome decision-making barriers

In addition to identifying the common barriers to decision-making as perceived by the port respondents, interviews also asked questions about how the barriers might be overcome. Analysis of interview transcripts shows five main strategies for helping decision-makers overcome barriers to adaptation: (1) Foster collaborations, (2) Make regulatory changes, (3) Conduct risk assessment, (4) Develop financial incentives, and (5) Use new technology to enhance communication network. In Figure 5, the resulting frequency measures correspond to the total count that respondents mentioned the strategy in the interview transcript. The percentages are calculated for the number of responses within each category of decision-maker.

Figure 5. Decision-makers' perceptions on the strategies that can help them overcome the identified barriers to adaptation. The value above each color is the percentage of respondents that mentioned that strategy within the decision-maker category (Directors/Managers, Environmental Specialists, Safety Planners). Red numbers are the total frequency of the responses (n = 30). Red-outlined sections represents the overall percentage of responses for a barrier. (Graph credit: J. Menendez Lopez).



4.3.1 Strategy 1 – Foster collaborations

4.3.1.1 Description of Strategy 1

Twenty-two of thirty respondents mentioned the foster collaborations strategy (Figure 5). Strategies coded in this category related to the promotion or encouragement of partnerships, as well as promoting public engagement. Six sub-categories were clustered within this strategy, as follows: (1) Foster collaborations (in general terms), (2) Education opportunities to understand risk, (3) Form public-private partnerships to pay for improvements, (4) Partner with academic groups to research adaptation, (5) Form a resilience working group, and (6) Develop risk assessment or include risk and adaptation plans in port's master plans (Table 9).

Most port decision-makers favored *fostering collaborations* as a strategy to remove the barriers. Through collaborations with academics, port decision-makers could reduce uncertainty by gaining knowledge of scholarly works on the range of negative impacts on social-environmental systems and the increasing risk to storm impacts in coastal areas due to climate change (USDOT 2013; Hallegatte et al. 2013)

Table 9. Foster collaborations and its six sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Foster collaborations (73%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Foster collaborations (in general terms)	12		
Education opportunities to understand risk	18	38	
Form public-private partnerships to pay for improvements	41	50	40
Partner with academic groups to research adaptation	41	25	20
Form a resilience working group	12	38	40
Developing risk assessment or include risk and adaptation plans in port's master plans	24	63	40

Social scientists have highlighted the importance of collaborations in promoting "strategic thinking, resourcefulness, creativity and effective communication" (Moser and Ekstrom 2010; page 22,030). In the context of responding to storms and natural hazards, many ports already collaborate with state emergency response and management entities, federal emergency management agencies, the USCG, the Department of Transportation, as well as the Department of Homeland Security. Respondents mentioned that they benefit from these collaborations and from accessing locally relevant information, both of which inform their resilience planning. "We will participate with anybody who wants to do anything on the climate resilience topic. We have participated with the Department of Homeland Security on critical infrastructures assessment, and I think that that helped us understand our own infrastructure better." (ES30)

Promoting education opportunities that help individuals and groups understand the risk and knowing how that information needs to be communicated—different individuals may need different information, and have it explained in different ways— is very important, as noted by several respondents:

> Creating a clearinghouse of the multiple views of climate change and climate resilience can be very powerful . . . some folks are comfortable on a planimetric view and will be able to see the scope and scale of the impact. Others are going to need to see it in sections. Not everybody has the facility to understand all graphic forms and some just need the information in table and narrative form. (ES30)

> We have a set of protocols that we developed last year after a flooding event . . . a rain event. With the new protocol, we do a better job at watching the weather, changes in the tide, then communicating inter-departmentally and giving notice to the public when we know that there is going to be an event. (ES30)

Respondents also shared how public-private partnerships help them contribute to the sustainability of other sectors.

> One of the things that we are doing in our pier rehabilitation project, because we have an aquaculture facility just to the north of our pier, we are working with the owners of that aquaculture farm and we are probably going to relocate them—at our expense—to make sure that they can continue to harvest clams of the bay ... and keep their business alive and to keep people working so that there is no harm to the environment, while we do our construction, and then we will move them back. (DIR1)

Having learned from experience, some respondents mentioned collaborations around short-term actions that sustain regular operations or address SLR. The short-term actions included (1) implementing best management practices and procedures, (2) doing pier rehabilitation, (3) raising the pier, (4) conducting flood mitigation projects, and (4) conducting assessments of critical infrastructure. With the presence of port resiliency groups and the integration of their new risk assessments into their master plans, some respondents reported that they are making progress in their climate and extreme weather planning:

> The city planning department did recently [complete] a hazard mitigation plan. This was adopted in 2016. It is not fully developed yet. In this plan, they identified some of the issues and worked with the Public Works department, the engineer's office, the water pollution control agencies. (DIR7)

Current strategies in collaboration with the USCG focus on preparing the port prior to an imminent storm, as respondents mentioned:

> We got a really good maritime team in the region that is overseen by the USCG. They take the lead on preparations for an imminent storm. They have pulled all the players in and they have really brought an awareness, so that we are all thinking about being prepared all the time. (DIR14)

> I think what we are doing well now to increase the port's resilience to storms is the planning, and it is the training and the drilling we do to ensure that boat operators understand the processes. With the training and mock preparations [across terminals, departments and port operators], [we] are also able to make any corrective actions. (SP6)

4.3.1.2 Responses by decision-maker type

There was high agreement about strategies in the category of fostering collaborations. A total of 23/30 respondents mentioned it (12 directors, 7 environmental specialists, and 4 safety planners). The one difference in responses was on how collaborations could promote education opportunities to help port staff understand potential risk. This was mentioned by directors and environmental specialists but not by safety planners.

Together with collaborative approaches, a government approach is needed so that adaptation efforts are facilitated and supported at the state and national levels (Mukheibir et al. 2013).This process would benefit governments being empowered, establishing better communication flow, and transfer of information. Studies also suggest that adaptation efforts benefit from stakeholder engagement and participation (Wilbanks and Kates 1999; Eakin and Luers 2006).

In the North Atlantic region, there are many examples of collaborative efforts (Becker and Caldwell 2015). Brown University and the University of Rhode Island are institutions conducting research around the Port of Providence along with the University of Rhode Island's Coastal Resources Center (Becker and Caldwell 2015). At a larger scale is the Infrastructure and Climate Network in New England, which brings together practitioners and scientists from multidisciplinary fields. This comprehensive regional collaboration integrates multiple sectors of the transportation system, including ports.

4.3.2 Strategy 2 – Make regulatory changes to encourage resilience

4.3.2.1 Description of Strategy 2

The strategy to make regulatory changes to encourage resilience was mentioned by 20/30 respondents (Figure 5). This strategy calls for the creation, or enforcement, of legal framework that would support or pressure port decision-makers to adapt ports to climate and extreme weather events. There were three sub-categories mentioned: (1) Develop guidance (from USCG), (2) Regulations force resilience measures, and (3) Renovation and upgrades integrate SLR considerations (Table 10).

Table 10. Make regulatory changes to encourage resilience, and its three sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Make regulatory changes to encourage resilience (67%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Develop guidance (from USCG)	47	25	
Regulations force resilience measures	24	38	
Renovation and updates integrate SLR considerations	6	50	20

Regulatory changes are to be long term in their scope. Because of this, respondents suggested that they be based on the best available data (i.e., scientific projections about the potential of SLR, storms, etc.). This strategy was mentioned in the context of the development of a 30-year long-term master plan and the ports' continued collaboration with USCG guidance and updates on the technology that generates weather-related data. One example is the following:

> This [response to a storm or weather impact] is really a whole of community approach. When there is a big storm, a hurricane tracking, or what is predicted to be a very strong northeastern, the USCG captain of the port will get all the major stakeholders together. This includes the US Navy, and our folks on the operations and the emergency operations side. This also includes the boat pilots, some of the major consumers and users of the waterfront. They will all get together and . . . set different conditions within the port. This is a very prescriptive USCG kind of thing. (DIR11)

Another example is the following:

> Typically, both the state and city need to be involved in resilience investments said one respondent, explaining that ". . . to make those resilience investments, it might just have to be driven . . . the state and the city [need] to start to consider these adaptations." (ES2).

4.3.2.2 Responses by decision-maker type

A total of 12 directors, 7 environmental specialists, and 1 safety planner mentioned *make regulatory changes* to encourage a resilience strategy (Figure 5). The only distinction in their responses was that both the directors and the environmental specialists mentioned this in the context of developing guidance from the USCG and regulatory changes, while the safety planner's response focused on how adaptation could be addressed by factoring in SLR when renovating facilities in the future: "Youll see as facilities are renovated or new facilities are constructed, that they will factor in SLR." (SP6*)*

Environmental specialists and safety planners favored *regulatory changes* as a needed strategy for adaptation (Figure 5). The role of governance – responsible *actors* that are actively engaged cannot be underestimated. In the absence of active leadership in port resilience efforts, regulatory changes that align with a resilience mandate could influence the allocation of resources to both safeguard the port and serve the surrounding areas and communities.

4.3.3 Strategy 3 – Conduct risk assessments

4.3.3.1 Description of Strategy 3

Conduct risk assessments as a strategy to overcome barriers to adaptation was mentioned by 17/30 respondents (Figure 5). The strategy is defined as the action of documenting, and acknowledging, the risk factors at a port — a fundamental step in understanding the vulnerability of a port and its facilities.

There are three sub-categories within this barrier: (1) Learn from experiences, (2) Train for emergency response, and (3) Undertake holistic risk assessments (Table 11).

Table 11. Conduct risk assessments, and its three sub-categories. Numbers in the rows are percentages of the total number (n = 30) of the respondents in each decision-maker group that mentioned a strategy in the category at least one time. Colors denote high agreement (green), to low agreement (orange), to zero mentions (gray).

Conduct risk assessment (57%)	Directors and Managers	Environmental Specialists	Safety Planners
	n = 17	n = 8	n = 5
Learn from experience with storms	47	63	60
Train for emergency response	6	25	
Undertake Holistic Risk Assessment	6	75	40

Having learned from the recent passing of Hurricane Sandy (2012) (Appendix G), some respondents indicated that they are making resiliency upgrades. Comments from directors include “You know, it was short term, but think and extrapolate that SLR projection to a longer-term period and you would have flooded terminals on a frequent basis. [That frequency of] flooding . . . would interrupt the free flow of goods regularly" (DIR11). "To address SLR, the only thing I can think of is taking the current port management plan that we have and try to adapt it based on [the need for] higher grounds" (DIR3). Other directors and safety planners had similar comments:

> Our city has a dedicated marine unit in the police department and the fire department also owns vessels that they use to train on a regular basis. They have docks so that they can put out fires on vessels or on shoreline infrastructure. There is also a diving team that trains regularly for search and rescue . . . (DIR5).

> . . . the port has done some assessments and they are incorporating it [information from the assessments] into long-term planning . . . We did an assessment for the port and there was a location where they wanted to put an IT [information technology] backup. They wanted to use a small building, and when they realized that that could flood just a little bit, they decided to move it elsewhere . . . (SP6)

> The port is trying to avoid … an unexpected occurrence that causes the shutdown of operations in the middle of the day and results in a logistics nightmare. The goal is . . . to eliminate the disruption or the potential for the disruption. (SP6)

A port's facilities, warehouses, and even their stormwater management systems are candidates for impact, as one director says, "If we had a storm like Sandy, I would fear the warehouse would be impacted at its current elevation level" (DIR4). Another spoke in more detail about what his port is doing:

> Part of the projects that we are working on—we are handling some stormwater management upgrades on our docks, on our wharfs—we are getting CDS [Continuous Deflective Separation] units, which handle floatables, and we are also rebuilding our wharves to handle surges/flood issues. So, we have been working on that and we have been incorporating the thought process [on SLR risk and how to prepare for them] into our projects as we move forward. (DIR4)

Some port decision-makers mentioned the importance of training in emergency response and conducting drills on the deployment of protecting-devices such as ". . . aqua-fans devices and armor[ing] certain facilities and buildings with them" as early actions to protect against those things that could happen immediately (DIR28). "Since super-storm Sandy, we . . . purchased the aqua fences, all ready to be deployed around substations, transformer facilities and [have taken] other measures both in the port and at the airport" (DIR28).

Another spoke of the need to ensure the individuals procuring new resilient equipment or designing more resilient facilities know what is needed and they "understand what it needs to have to make it resilient and to make it conform with the long-term viability [of the port]" (DIR11).

4.3.3.2 Responses by decision-maker type

Eight directors, six environmental specialists, and three safety planners mentioned conducting risk assessments as a strategy (Figure 5). The environmental specialist and the safety officers put a higher emphasis on this strategy than did directors, highlighting lessons learned from Hurricane Sandy (2012) and the need to not only focus on a similar impact but to undertake a more holistic risk assessment. Of all the responses, environmental specialists were more systematic in their approach to understanding resilience. They integrated concepts from engineering, mentioned the use of three-prong approach, and highlighted the need for more data to run risk models and cost-benefit analysis. The three-prong approach includes (1) wherever possible, relocate non-essential activity out of the flood plain; (2) if that was not possible, commit to elevate structures and sensitive infrastructure two feet above the hundred year flood plain for their basin; and (3) if that is not possible, then make sure that moving forward, new upgrades were better, and used non-corrosive, stronger materials that can hold up to extreme weather.

Having information is important, one respondent mentioned, "I think, from a planning perspective, it would be helpful to have more information to run the models on risk and cost-benefit based on risk" (ES10). "We just did finish a resiliency study . . . and it was looking at some of the hard infrastructure and potential issues we could have here for tidal surge and flooding. (ES12). Another environmental specialist spoke about how conducting risk assessments helped them better understanding the risk:

> The potential for impact has been presented to leadership in the city's staff, and we now have a better idea of how to talk about

> adaptation . . . Taking a three-pronged approach at a concept level, we now have a better understanding of the engineering and what we need to do; we have a better understanding of what the impacts will be; and we are more conversant in the process. (ES30)

4.3.4 Strategy 4 – Develop financial incentives

4.3.4.1 Description of Strategy 4

Development of financial incentives was mentioned by 15/30 respondents as a strategy (Figure 5). These included eight port directors, six environmental specialists and one safety officer. Respondents in this study perceived that financial incentives could facilitate needed adaptations at the port. The political nature of local government means that all decisions, including climate adaptation, are affected by political interests and competing preferences vying for support at the municipal scale (Keen et al. 2006).

Because port resources are generally used for standard maintenance and day-to-day operations, it is easier to persuade tenants and others that adaptation is worthwhile if there are also financial incentives for making adaption(s). Incentives can come from grants or federal or state government agencies. One director felt "The only way that we have been able to achieve that [adaptation] is through getting funding through the federal government" (DIR18).

Incentives can come also from insurance companies — in the form of reduced insurance premiums tied to a port's increased resilience to hazards, as described by two respondents:

> Financial incentive is always an easy driver for a lot of the tenants and people within agencies . . . to convince them that [adaptation measures] are worthwhile . . . tenants come to us requesting what guidelines they should follow, since they are working and operating on our facilities . . . I have prescribed to them that they discuss [with their insurance provider] whatever requirements are pertinent . . . a lot of times the cost saving can be dramatic, even just by going up . . . half a foot more in elevation. (DIR23)

> [We need] more financial [incentives] and it would have to be from a State or federal level. (DIR3)

4.3.4.2 Responses by decision-maker type

Eight directors, six environmental specialists, and one safety planner mentioned the development of financial incentives as a strategy to remove the barriers to adaptation. Safety planners summarized this in just two words, "money and resources," what they considered most needed for adaptation (SP13).

4.3.5 Strategy 5 – Use new technology to enhance communication networks

4.3.5.1 Description of Strategy 5

The use of new technology to enhance communication networks was mentioned by 6/30 respondents (Figure 5). These included four port directors and two environmental specialists. This strategy refers to enhancing available information through the acquisition of real-time data or using available models to project weather in advance. For instance, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Services, and other agencies provide real-time local weather data or modeled projections that increase port decision-makers' ability to predict in advance and prepare for a given weather condition.

Twenty-four percent of the directors and managers mentioned using new technology to enhance communication networks as a strategy to remove barriers to adaptation. For example, one director stated, to the important role of federal agencies, "We get a lot of information from NOAA, different sorts of agencies that monitor buoys and collect data along the coastline, and . . . that data are aggregated into information that they can provide for us" (DIR 18). Another director elaborated with the following:

> We have NOAA PORTS[1] program; it is the physical oceanographic real-time system. Basically, we got sensors out there, available to the public on the internet, to tell you the exact state of the tides, and we have a sensor on the . . . bridge that will tell you the exact distance from the bottom of the bridge to the water on that bridge. (DIR8)

[1] This is a NOAA initiative program, Physical Oceanographic Real Time System (PORTS). For more information, go to **https://oceanservice.noaa.gov/facts/ports.html**.

> Because we keep track of the weather . . . several times a day . . . we know a storm is threatening, we take precautions. (DIR9)

Twenty-five percent of the environmental specialists mentioned using new technology as a strategy to remove barriers to adaptation. They mentioned using data networks to inform goals and decision-making. In one of the ports, the emergency response is orchestrated through a marine instant response team that coordinates different sides of port operations and port safety personnel, connecting with agencies both outside and inside of the port. Several environmental specialists spoke on this issue:

> We are a team of folks, and we have a marine instant response team on the terminal that coordinates with our safety folks and operations folks. I get involved from time to time as well. Our development coordinator gets involved . . . Basically, you have some representatives there from each terminal, representing each department for the most part. Then they coordinate with outside entities like the USCG or the Department of Emergency Management (DEM) at the state level. (ES 12)

4.3.5.2 Responses by decision-maker type

Decision-makers in this study mentioned different short-term actions that were being implemented to increase the resilience of their ports to natural hazards. Some of these included implementing best management practices and procedures and updating port management plans to include risk assessments or putting in place a Risk Assessment of Critical Infrastructure document. Environmental specialists also saw the potential in ports to become greener and more sustainable, playing their part in being supportive of green industries. As an example, ports are taking steps to reduce their carbon footprint by encouraging the acquisition of new trucks. Some ports are capitalizing on the transportation of wind turbine equipment, and there was mention of leveraging the port's building space for solar power industries. One environmental specialist mentioned how using the port infrastructure as a resource could potentially help them finance climate and extreme weather adaptation.

Other short-term actions include implementing pier rehabilitation projects, raising the pier to FEMA standards (or above when resources are available), and conducting flood mitigation projects. To address adaptation, the strategies to assist port decision-makers in removing or managing the existing barriers were assessed.

The results of this study represent a subset of decision-makers for 15 medium-use and high-use ports in the North Atlantic. Responses on climate and extreme weather adaptation barriers and strategies need to consider the location and geographical conditions as relates to the natural hazards that ports are experiencing. More work is needed to integrate a larger number of port stakeholders in the conversation, to make clear connections not only on what the barriers are but also on who has the responsibility to remove them (Biesbroek et al. 2013). Efforts should expand to understand risk both at the port and their neighboring communities. The development of the approach and research methods used in this study can be used in other regions to measure consensus on barriers to adaptation and the strategies.

5 Recommendations

As more studies address processes and challenges of implementing climate and extreme weather adaptation, the imperative to understand barriers at the port level is still fairly new. This study addresses the need to quantify barriers to understand the ability of ports, and communities, to adapt to a threat of coastal hazards. Earlier sections summarized port decision-maker perceptions of the barriers to climate and extreme weather adaptation and their opinions on strategies to help overcome these. This section reflects on some of those results and provides recommendations to help decision-makers address adaptation barriers.

Although barriers to adaptation will always exist, the magnitude of damages in the coasts and critical infrastructure can be reduced through the implementation of climate and extreme weather adaptations (Füssel 2007). Hence, U.S. port operators, who hold the primary responsibility for resilience planning (Becker and Caldwell 2015), can minimize the port's vulnerability to natural hazards by implementing adaptation strategies (Nicholls et al. 2008).

The presence of adaptation barriers in the decision-making process is not unexpected. However, barriers, especially those that are social in their nature, can be overcome through political will (Adger et al. 2008), through support, resources, and effort (Moser and Ekstrom 2010). In the past, as ports developed and built their infrastructures, decision-makers used probabilities and projections known to them and invested in technologies and energy sources that were available then. With current changes in climate and extreme weather events, the uncertainty of these events increases the risks and vulnerability of ports, coastal infrastructures and their communities.

This study specifically addresses port decision-makers' barriers to adaptation because decision-makers play a significant role in reducing risks and building the resilience of their ports. Port decision-makers already know that failure to implement climate and extreme weather adaptation would result in the following:

- ports being vulnerable to floods, wind impacts, more severe storms, etc.
- loss of business due to shutdowns

- loss of connections to other infrastructure (i.e., roads, rail).

By participating in addressing barriers to adaptation and seeking to understand the risks and the benefits of adaptation, the three decision-maker categories directors, environmental specialists and safety planners can enhance the resilience of their ports. In the recommendations that follow, the concerns that the decision-makers highlighted (Figure 3) are matched with some of their identified strategies (Figure 5) and adaptation approaches identified in the literature. Often times, addressing one adaptation barrier will overlap with solving for other barriers.

To address the barriers of lack of understanding of the risks and governance disconnect, port decision-makers could (1) institutionalize climate and extreme weather adaptations, (2) conduct risks and environmental assessments, and (3) foster collaborations.

5.1 Institutionalize climate and extreme weather adaptations

Institutionalizing adaptations generally means including such strategies in management plans, along with strategic plans and budgets to allocate resources for adaptation and mitigation (Zambrano-Barragán et al. 2010). These two barriers of concern are best addressed by making regulatory changes, changes that require stable local leadership (Ekstrom and Moser 2014), and support from higher levels of governance (Rudberg et al. 2012), as well as establishing an institutional framework to address adaptation on an ongoing basis.

One of the most important steps a government can take to prepare for present and future extreme weather events is “the inclusion of adaptation and mitigation in annual operative plans and budget allocations” (Zambrano-Barragán et al. 2010; page 1). Climate adaptation will always be affected by political interest contesting for support from municipalities (Keen et al. 2006) because regulatory change strategies are most often long term in their scope, and political agendas are short term in their scope, the inherent uncertainty of climate projections makes this difficult (Stocker 2013).

The role of port directors, their leadership and direction in the processes of adaptation, is critical to the reduction of risks at the port level. In the absence of an appointed state individual who oversees climate and extreme weather actions, port directors can (1) appoint individual(s) that can lead and coordinate climate and extreme weather adaptation in their ports and (2) together, the director, the appointed individual(s) — or a committee — can draft a framework for the planning and inclusion of other port stakeholders. These steps would serve to outline collaborations and links to information on national weather, availability of funds and opportunities, and research collaborations.

Zambrano-Barragán et al. (2010) stated that to address the adaptation barriers, strategies should include the development of flexible social institutional frameworks as a basis for decision-making, and the development of policies that are based on experience, that are relevant to many possible future scenarios, as well as be informed of numerous factors affecting societal change (Rayner and Malone 1998; Sarewitz and Byerly 2000). An inspired leadership, Burch writes, could significantly change the context of decision-making by establishing innovative governance models (Burch 2010).

Institutionalizing climate and extreme weather adaptations also addresses decision-makers concerns for lack of funding and physical constraints, given that mitigation and adaptation would be included in annual budgets. Although this pilot study does not investigate or present current policies on climate and extreme weather adaptation for ports, the understanding and characterization of barriers need to be seen in the context of available policy options (Lempert et al. 2004) and in the context of societal changes (Rayner and Malone 1998; Sarewitz and Byerly 2000). Making regulatory changes was recorded as the second (20/30 frequency in responses; Figure 5) strategy to overcome adaptation barriers. This strategy was of great importance to environmental specialists who see the port within a system that is interconnected with the environment.

It is noted in the literature that decision-makers often consider and adopt adaptation strategies that are in alignment with their own values and political interests. Decision-making is influenced by “how people perceive, interpret, and think about risks and their management, what information and knowledge they value,” etc. (Moser and Ekstrom 2010; page 22,029).

To decrease the *lack of understanding*, increase *communication* and address why the *perceptions of risk do not exceed an action threshold* decision-makers could do the following:

- Conduct risk and environmental assessments
- Foster collaborations.

5.2 Conduct risks and environmental assessments

Port **environmental specialists** and **safety planners** would have a role to play in the development of ongoing risks and environmental management plans. Environmental specialists, in this study, highlighted lack of understanding of risks and physical constraints as the top barriers of concerns. Safety officers mentioned that perceived risks did not meet an action threshold and the lack of funding as the barriers of most concern to them. All decision-makers saw opportunities and benefits for establishing collaborations and partnerships with researchers and people in government agencies who could help them increase their understanding of climate change and extreme weather impacts, as well as elaborating risk management plans for their ports that integrate data from government sources. As Biesbroek et al. (2011) identified earlier, there is great need for public and government support in climate adaptations.

Safety planners in this study — perhaps — being more cognizant of risk conditions at their ports, rather than highlighting the need for *conducting risk assessments*, most frequently mentioned *fostering collaborations* and *making regulatory changes* as strategies to overcome adaptation barriers. Fankhauser et al. (1999) mentioned that decision-making processes that provide the right information, resources, and skills to people can increase their resilience and ability to adapt to climate change in a reliable manner. Collaborative research and information gathering can provide guidance that is key to decision-making process under uncertainty (Zambrano-Barragán et al. 2010). Some climate-related information like meteorological data, models, and predictions, together with historical, geographical, and socio-economic information, are central for adaptation processes (McGray et al. 2007).

While it may be impossible to eradicate uncertainty, the acquisition of knowledge could turn reactive responses into proactive planning. Through a better understanding of weather trends and frequency probabilities, decision-makers can respond to storm events by delivering effective strategies that reduce risks and respond to present and future climate and extreme weather changes in an informed manner.

5.3 Foster collaborations

To foster collaborations and establish partnerships are the base of decision-making for climate and extreme weather adaptation (present and future). Aside from mentioned collaborations with academics and government agencies, decision-makers benefit from the guidance and feedback from policy makers and insurance providers. One of the greatest advantages of collaborations is the shared burden of plans and actions, where resources, time investments, and expertise can be shared (Zambrano-Barragán et al. 2010).

Reaching out to others, port decision-makers can learn to maximize future investments and become aware of best available data that enable them to make informed decisions. This can be instrumental for the development and implementation of resilient strategies that are effective in reducing risks of ports to climate and extreme weather impacts. There will be port administrations and decision-makers that have not yet experienced an extreme event. Furthermore, public engagement brings stakeholders to the forefront. Stakeholders' involvement in participatory forums and programs is key to early identifying local concerns. Participatory processes strengthen the social and political base for effective implementation of policies and decisions that consider general priorities of all, the short-term, long-term responses and tradeoffs of the decision-making processes (Zambrano-Barragán et al. 2010).

Conducting risk and environmental assessments are closely intertwined with fostering collaborations and partnerships because of shared interests. Through these collaborations there is an opportunity for technology and innovation, the use and development of existing tools, and strategies and mechanisms to enhance operations and communication. An increase in the institutional capacity and the knowledge of potential risks paves the way for planning strategically; addressing concerns and infrastructures vulnerabilities on a regular basis would make the problem of climate and extreme weather impacts less overwhelming.

Because decision-making itself can be a barrier to adapting to climate and extreme weather, decision-makers play a significant role in reducing risk and building the resilience of their ports. As noted by the National Research Council (NRC), effective adaptations for climate change need all types of decision-makers and stakeholders to participate (NRC 2010). Increasing institutional capacity in the ports can promote the advancement of informed decision-making guidance and knowledge needed to execute on adaptation planning and risk management. In the table below, additional recommendation actions are outlined for each different decision-maker type (Table 12).

Table 12. Other recommended actions that port decision-makers can take in function of their positions at the ports.

Port Directors and Managers	Environmental Specialists	Safety Planners
(1) Work with regulatory agencies to develop regulatory changes that encourage resilience and provide financial incentives.	(1) Integrate climate risk assessments into the port management plan.	(1) Integrate climate risk assessment into the port management plan.
(2) Lead managers, port operators, and others in organizing and establishing working groups and developing emergency response strategies (flood barriers, etc.)	(2) Organize working groups to address climate risk.	(2) Organize working groups to address climate risk.
(3) Promote learning opportunities, acquisition of data, and communication tools to enhance understanding of risks.		(3) Organize drill exercises to enhance the ability of port personnel to respond to natural disasters.
(4) Direct working groups to update port master plans to include relevant SLR projections and/or to develop risk assessments.		

An incremental approach to adaptation strategies can be thought of as “extensions of actions and behaviors that already reduce the losses that can enhance the benefits of natural variations in climate and extreme events” (Kates et al. 2001). Directors, environmental specialists, and safety planners, together with port administrators and a growing number of informed stakeholders, in time and with practice, can achieve a balance in the implementation of the adaptation processes, understanding the barriers, evaluating possible strategies, and carrying out their implementation and evaluation.

The contribution of this research builds and integrates knowledge on port decision-makers’ barriers to adaptation and strategies to help them remove these. The results of this study represent a subset of decision-makers for 15 medium-use and high-use ports in the North Atlantic. Responses on climate and extreme weather adaptation barriers and strategies need to consider the location and geographical conditions as relates to the natural hazards that ports are experiencing. More work is needed to integrate a larger number of port stakeholders in the conversation, to make clear connections not only on what the barriers are but also on who has the responsibility to remove them (Biesbroek et al. 2013). Efforts should expand to understand risks at the port and their neighboring communities. The development of the approach and research methods used in this study can be used in other regions to measure consensus on barriers to adaptation and the strategies.

6 Conclusions

The results of this pilot study suggest that North Atlantic medium- and high-use port decision-makers' perceived barriers to climate and extreme weather adaptation fall into seven categories, and their proposed strategies to address fall into five categories. The 30 interviewed port decision-makers have consensus on the barriers that prevent them from implementing resilient adaptations. This shared agreement is fundamental for the understanding of risks to storms and extreme weather events that are impacting, and will continue to impact, coastal infrastructures. Port authorities and port administrators, together with state, federal, and private agencies, can help port decision-makers in planning actions to reduce or remove the barriers to increase the resilience of their ports in a holistic manner. Through the fostering of collaborations, the burden of plans and actions (resources, time investment, and expertise) can be shared. Greater involvement of port tenants, and diverse port stakeholders, would increase the understanding of the risks and generate a greater sense of responsibility. A first step in the process of resilience building is drafting/revising emergency management plans and/or risk assessment plans.

Barriers to adaptation will always exist. However, today's decision-making will increase or decrease the future adaptive capacity of the country's ports. The ability to take gradual steps in incremental adaptations will better prepare port administrators in sustaining their missions while facing increasingly challenging climate conditions and increasing extreme weather incidents. Port decision-makers should reach out to policymakers, insurance providers, and others to help maximize future investments and extend the resilience and lifetime of the ports' infrastructure.

By interviewing different key experts in each port, consensus on whether their ports are threatened by climate and extreme weather events is quantified, and the perceived barriers to extreme weather adaptation and the concept of seaport vulnerability are characterized. Also, the practices and circumstances that are locally relevant across the studied ports can be determined. The methodology used in and the insights resulting from this pilot study can be applied to other areas/categories in the future, providing a *road map* for tactics to address the adaptation barriers and the strategies to address them — addressing the shortfall of adaptation strategies for adaptation to extreme weather currently available to ports.

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Appendix A: Port Decision-Makers' Perceptions on Climate and Extreme Weather Vulnerability

Ground truthing in this study follows the development of a quantitative vulnerability index for ports (McIntosh et al. 2019). The index can be used to assess relative vulnerability measurements across multiple ports, identifying those at higher risk to impacts from extreme weather events. Along with the vulnerability index, identification of barriers to extreme weather adaptations can help in understanding the concerns that may impede the development of resilient ports. The value of the model is strengthened by ensuring the results capture stakeholders' input and local circumstances and practices. This helps in identifying the barriers to adaptation that are most relevant to those working in a port. Further, the involvement of decision-makers in the development process increases the likelihood that study outputs will be integrated into their local decision-making processes.

Responses by decision-makers on their understanding of the vulnerability of the ports were organized using the IPCC definition of vulnerability (Appendix E).

Although all groups mentioned vulnerability in terms of adaptive capacity, the assessment on decision-makers' perceptions of the concept of port vulnerability found that a majority (80%, 24/30) explain it in terms of exposure and sensitivity (Table A-1). However, safety planners had the largest percentage of its group (80%, 4/5) link vulnerability and adaptive capacity. An explanation could be that these individuals, who address port safety daily, most clearly see the connection between adaptive capacity and the ability to respond to an extreme weather event.

Table A-1. Distribution of the responses by the three categories of decision-makers. Values are presented in the percentages for each group of respondents. The total number of respondents was 30.

Components of Vulnerability	Directors/Managers (N = 17)	Environmental specialists (N = 8)	Safety Planners (N = 5)
Exposure	82.4%	75%	80%
Sensitivity	70.6%	87.5%	100%
Adaptive Capacity	17.6%	25%	80%

Port exposure to climate and extreme weather events was explained in terms of exposure to SLR, high winds, blizzards, and flooding events that could impact the physical infrastructure, facility, and cargo and that could also affect vessels, people, and systems. Disruptions would slow down, delay, or prevent the port's functioning, affecting the economic viability of the port and its ability to deliver goods. Together with the port, waterfront properties, waterways, and marshlands are also viewed as vulnerable and exposed. Similarly, in sensitivity terms, these surrounding areas, local population, and key ecosystems would have a higher frequency of rain, storm, and surge impacts. Beyond impacts to physical infrastructure, extreme events also generate social and economic impacts. Depending on the nature and verity of the storm and the force of winds, the port's function could be delayed or crippled. The weather event could also cause long-term physical damage and shut downs. Stored cargo could be destroyed or lost. Coasts could experience erosion, and channels could accumulate more than the usual sediments.

This appendix explains that a port's level of vulnerability, in terms of adaptive capacity, is strongly tied to its decision-makers' understanding of the risks and potential impacts and acting upon that knowledge. This is of interest to this study, as the adaptive capacity element of the vulnerability component had the lowest ranking during the expert evaluation process (McIntosh et al. 2019). As mentioned earlier, study respondents most often explained vulnerability in terms of a port's exposure and sensitivity. Few explained it in terms of adaptive capacity (Table A-1 of this Appendix A).

In addition to explaining vulnerability as it relates to climate and extreme weather (Table A-2), some respondents mentioned their concern that the port's tank farms could be vulnerable to terrorism.

Table A-2. Decision-makers' perceptions on the vulnerability of ports.

Vulnerability Component	Decision-Makers' Vulnerability Perceptions
Exposure	Exposure to natural hazards, SLR, higher frequency of rain, storm surge, floods, heavy wind, blizzards. Impacts on physical infrastructure (e.g., tank farms), water ways, waterfront properties, coastal degradation, connectivity systems, peoples, the economy. In general terms, impacts on port functions, damage to facility equipment (e.g., containers knocked down by heavy winds), disruption of connectivity systems (e.g., trains over marshlands), delivery of goods. (Impacts may vary as a function of the age of infrastructure.)
Sensitivity	Sensitivity to natural hazards (see exposure). Impacts on physical infrastructure (tank farms, containers), coastal landscapes, navigation, accumulation of sediments in the channels. Degree of impacts. The sensitivity of the port is a function of the severity of nature (e.g., what the storm brings). This is also influenced by the elevation of the landscape, age of infrastructure at the port. Once impacted, ports are affected with delays, damage, destruction, loss or crippling of the port's functions. When ports lose their connections to people and waterways, this results in economic loss, shut downs, absence of goods (e.g., heating oil). Hence, all port stakeholders and their connection systems are susceptible,
Adaptive Capacity	In general terms, port is described as being prepared, having knowledge and awareness of risks, having the ability to restore functions and ensure business continuity. Planning. Knowledge that mitigation makes a difference in the port's vulnerability Active. Port has a contingency plan or an Office of Environmental Management.

Appendix B: Communication Inviting Participants

Subject: **IMPORTANT** URI Seaport Resilience Project

Dear Decision maker [Name],

My name is Dr. Elizabeth Mclean; I am a research associate in the University of Rhode Island's Marine Affairs Department, where I specialize in port resilience and extreme weather adaptations. At URI we are conducting a series of interviews with port representatives as part of a funded study with the USACE's Engineer Research & Development Center to understand seaport vulnerability to extreme weather events.

We are speaking with key port decision makers about long term planning and investment for resilience (see attachment). We are interviewing port directors/ managers, safety planners and environmental risk specialists at the 23 medium and high-use ports of the USACE North Atlantic Division who have knowledge about extreme weather planning and/or investments. Ten ports have already participated in our study. **Please let us know when you are available,** your input is highly valued and essential to this research!

I can be reached at 401-874-7083.

Thank you in advance,

Elizabeth Mclean

Elizabeth L. Mclean PhD, Research Associate | Department of Marine Affairs | Coastal Institute | University of Rhode Island

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http://web.uri.edu/abecker/dr-elizabeth-mclean/

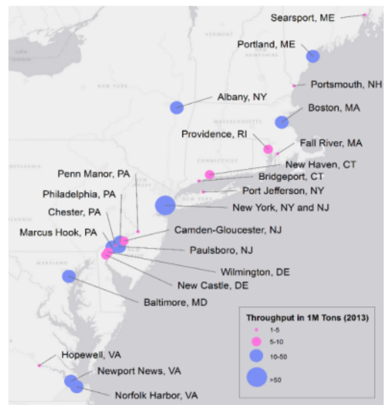
"A mechanism of world intercommunication will be devised, embracing the whole planet, freed from national hindrances and restrictions, and functioning with marvelous swiftness and perfect regularity." Shoghi Effendi 1936

Appendix C: Project One-Pager Description Shared with Port Decision-Makers.

Decision - maker Barriers to Extreme Weather Adaptation for Seaports: A "Cultural Consensus Model" for Medium and High-Use Ports in the North Atlantic

To assist government agencies and private firms to understand and prepare for extreme weather events and increase the port community's resilience, this project assesses the barriers to extreme weather events adaptation for the 23 medium and high-use ports of the USACE North Atlantic Division. Researchers are conducting a cultural consensus analysis of interviews with directors/managers, safety officers and environmental risk officers.

Heavy rains, storms, sea level rise (SLR), and extreme heat cause damage to critical coastal infrastructure upon which coastal communities depend. Seaport planners and managers need to plan and implement extreme weather adaptations and infrastructure protection plans to safeguard and enhance the resilience of their ports. However, recent investigations stress decision-making barriers slow the development and implementation of needed adaptation strategies.



USACE High and Medium-Use Ports in North Atlantic

Barriers, defined here as factors and conditions that impede, prevent or delay processes for the development and implementation of extreme weather adaptation strategies, can be overcome through planning, efforts, creative thinking and the prioritizations of resources. Barriers might include: a lack of funding, not enough information about the risks to ports, or a perception that other entities are better positioned to take the lead.

The Cultural Consensus Model (CCM) links distribution of a group's cultural shared knowledge to models of behavioral change. This project poses the question, "is there consensus on the barriers to adapt seaports to extreme weather?" and the perceptions stakeholders have on the concepts of vulnerability. Through a mathematical model, the CCM derives estimates of experts competence and an estimate of the cultural shared knowledge. It distinguishes patterns of socially transmitted knowledge that people use to interpret the world and to make decisions. Results will identify trends and gaps that port authorities and policy makers can address to facilitate resilience planning. In addition, through active engagement of these port stakeholders, the process of creating a CCM and dissemination of results can lead to increased levels of trust among the participants. By applying a CCM, we will contextualize and cluster perceptions and identify "cultural shared knowledge" about the barriers and make recommendations for constructive interventions.

This work builds on the USACE funded project "Measuring risks to inform resilience: Pilot study for North Atlantic Medium and High Use Maritime Freight Nodes". It responds to the call for increasing resilience and protection of national critical infrastructure by increasing our understanding of barriers to extreme weather adaptation.

Contact: Dr. Austin Becker or Dr. Elizabeth L Mclean | p: 401-212-1721 |
Web: http://web.uri.edu/abecker/risk-indices/

COASTAL INSTITUTE

ERDC

THE UNIVERSITY OF RHODE ISLAND DEPARTMENT OF MARINE AFFAIRS

THE UNIVERSITY OF RHODE ISLAND Social Science Institute for Research, Education, and Policy

Appendix D: Consent Form (IRB) and Interview Instrument

THE UNIVERSITY OF RHODE ISLAND

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COLLEGE OF THE ENVIRONMENT AND LIFE SCIENCES

DEPARTMENT OF MARINE AFFAIRS
1 Greenhouse Road, Suite 205, Coastal Institute Building, Kingston, RI 02881 USA p: 401.874.2596 f: 401.874.2156 cels.uri.edu/maf

CONSENT FORM FOR RESEARCH

PROJECT: Decision-maker Barriers to Extreme Weather Adaptation for Seaports: A Cultural Consensus Model for Medium and High-Use Ports in the North Atlantic

You are being asked to take part in a research study about decision-makers' perceptions of extreme weather adaptation for seaports. Your responses will be strictly confidential and help inform efforts toward to increase the resilience of ports and their surrounding communities.

The interview will take approximately 20 minutes. There are no known risks, benefits or compensation for participating. The decision to participate in this study is yours and you may refuse to take part in the study at any time without affecting your relationship with the investigators or the University of Rhode Island (URI). You have the right not to answer any single question, as well as to withdraw completely from the study at any point during the process.

You have the right to ask questions about this study and to have those questions answered by me before, during, or after the interview. You may also contact Prof. Austin Becker, the Principal Investigator, at (401) 874-4192. Additionally, you may contact the URI Institutional Review Board (IRB), the University of Rhode Island IRB may be reached at (401)-874-4328 or researchintegrity@etal.uri.edu. If you have questions regarding your rights as a research participant or with any questions, complaints or concerns which you do not feel you can discuss with the investigators, you may contact the URI Vice President for Research and Economic Development, **Dr. Gerald Sonnenfeld,** at (401) 874-4576.

You may keep this copy of the document for your records. You may also contact the researcher to request a copy. By agreeing to do this survey, you indicate that you have read and understood the above and volunteer to participate in this study.

Participants signature ____________________________ **Date:** _______________

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Mclean & Becker

Decision Maker Barriers to Extreme Weather Adaptation for Seaports: A Cultural Consensus Model for Medium and High-Use Ports in the North Atlantic

Demographics

1. Name of the port ________________________

2. What is your position? ____

3. Number of years you have been working as a port manager/safety planner/environmental specialist? _________

Understanding Barriers

4. Do you feel your port has done enough to address extreme weather concerns? (why or why not?)

____

5a. Does your port have a management plan that considers long - term planning for natural hazards resilience? (Y/N) ___

5b. Are there some short-term actions to be planned to increase resilience?

____

5c. Which, if any, extreme weather impacts does this address? Which other natural hazards? ____

6. What are some of the challenges to implement extreme weather adaptation actions at your port?

____

7. You mentioned challenges to implementing adaptation actions (Q7). What resources would enable you to overcome these challenges? _________________________________

8. What could happen to your port if needed adaptations to extreme weather were not addressed?

____

Conceptualizing Seaport Vulnerability to extreme weather impacts (the CCM)

1. What does "seaport vulnerability to extreme weather impacts" mean to you?

____

2. Which components of the physical infrastructure of your port are exposed to:

a. extreme weather tide-related flooding? ____________________

b. surge damage? ____

c. or extreme temperatures? ____

3. How would the *exposure* of your port change with a predicted sea level rise of 2 feet in the next two years?

____

4. How does your port prepare for an imminent storm (*Adaptive Capacity*)?

____

5. Compared to other ports in the North Atlantic, what is one thing your port is doing well to increase its ability to prepare to extreme events or natural hazards?

6. *Sensitivity* is explained by the level to which a system is changed or affected. This can cause problems or lead to new opportunities. What facilities of your port do you consider to be sensitive to extreme weather impacts? ______________________________________

7a. How do you think your port would cope if the sea level would rise by 2 feet in 2020?

____

7b. How does this prediction change in the face of a storm? ______________________

8. The following natural hazards are already impacting some ports in the US. Which ones are you most concerned about? How would you rank them? (4, high – 0, low):

___ Extreme Temperatures
___ Extreme Precipitation
___ Sea level rise
___ Extreme Coastal Storms (high winds and surge)
___ Tidal flooding

Other:

____

Appendix E: Terminology Used in the Study

Adaptation is defined as "any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"(IPCC 2012).

Barriers are defined as factors that delays or prevents actions and plans to implement an adaptation, or an investment towards resilience.

Cultural Consensus Model is a method used in the social sciences to distinguishe patterns of socially transmitted knowledge that people use to interpret the world and make decisions ((Romney et al. 1987)). It uses a mathematical model to derive estimates of experts competence and cultural shared knowledge ((Romney et al. 1987)).

Decision-makers for the purpose of this study, consist of port directors or managers, safety planners, and environmental specialists charged with decision-making in the chosen ports.

Indicators are measurable, observable quantities that serve as proxies for an aspect of a system that cannot itself be directly, measured (Gallopin 1997; Hinkel 2011).

Resilience is the capacity to prepare, resist, recover, and adapt to a disturbance, such as a major storm event (CARRI 2013; Rosati et al. 2015). Also, Walker posits the "ability of a system to absorb disturbance and still retain its basic function and structure" (Walker et al. 2006).

Risk is the probability of an event to damage critical components of the infrastructure. Although potential outcomes are often uncertain (IPCC 2014), these are often measured monetarily as it relates to the physical components of a facility/system, loss of function (interruptions), cost repair, and stabilizing conditions (debris removal, etc.).

Seaport here collectively refers to the collocated real property and infrastructure involved in the loading and unloading of cargo from maritime vessels. These are port, facilities, locks, etc. Lacking a universally accepted method for delimiting for port boundaries, and recognizing that some seaports span multiple counties, this study of port vulnerability considers a port as an inextricable part of its local socioeconomic and environmental systems.

Vulnerability is defined as “the propensity or predisposition to be adversely affected . . . including the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events” (IPCC 2012, p. 32).

Appendix F: Cultural Consensus Model (CCM) (output)

No. of negative competencies: 0
Largest eigenvalue: 14.282
2nd largest eigenvalue: 4.905
Ratio of largest to next: 2.912

The weak eigen ratio indicates lack of fit to the consensus model--most likely, your respondents are drawn from a mix of two cultures.

	Competence Scores 1
1	0.139
2	0.456
3	0.614
4	0.547
5	0.729
6	0.547
7	0.687
8	0.527
9	0.762
10	0.547
11	0.981
12	0.166
13	0.216
14	0.981
15	0.323
16	0.981
17	0.762
18	0.981

19	0.476
20	0.067
21	0.981
22	0.981
23	0.981
24	0.981
25	0.610
26	0.751
27	0.516
28	0.729
29	0.687
30	0.125

ITEM 1: Governance Disconnect

Response	Frequency	Wtd. Freq.
0	10	7.07
1	20	22.93

ITEM 2: Lack of Communication

Response	Frequency	Wtd. Freq.
0	28	29.51
1	2	0.49

ITEM 3: Lack of Funding

Response	Frequency	Wtd. Freq.
0	7	4.20
1	23	25.80

ITEM 4: Lack of Understanding of Risks

Response	Frequency	Wtd. Freq.
0	2	1.32
1	28	28.68

ITEM 5: Perceived Risks does not meet Action Threshold

Response	Frequency	Wtd. Freq.
0	9	5.79
1	21	24.21

ITEM 6: Physical Constraint

Response	Frequency	Wtd. Freq.
0	10	6.62
1	20	23.38

ITEM 7: Problem is Overwhelming

Response	Frequency	Wtd. Freq.
0	28	28.83
1	2	1.17

Answer Key

	Barriers to Adaptation
1	Governance Disconnect 1.00
2	Lack of Communication 0.00
3	Lack of Funding 1.00
4	Lack of Understanding of Risks 1.00
5	Perceived Risks does not meet Action Threshold 1.00
6	Physical Constraint 1.00
7	Problem is Overwhelming 0.00

Appendix G: Lessons Learned from the Port Authority of New York and New Jersey

THE PORT AUTHORITY OF NY & NJ

Super Storm Sandy Lessons Learned

1. Plan for the worst, hope for the best. Mother Nature is relentless.
2. Maritime Transportation System Recovery Unit (MTSRU) is invaluable in port wide recovery.
    a. Ensure adequate representation from all industry sectors with current contact information
    b. Keep contact information, forms, maps/drawings, specifications, EEI data from CART etc in paper copy.
3. FEMA flood maps are just a guide. Don't rely on them.
4. Most "hurricane" plans consider extreme wind and rain, not surge. Surge protection measures are very different and should be planned for.
5. Employees are your most important asset. Plan to take care of their families so that can help take care of the port (i.e. housing, employee welfare kits etc).
6. Have a "game plan" to get essential personnel out of their neighborhoods and on site (i.e. entry permits, emergency access credentials etc)
7. Majority of Maritime Critical Infrastructure / Key Resources (CI/KR) are owned by the private sector. Not eligible for FEMA assistance. Moderate incentive to invest in mitigation measures for a "100 Year Storm."
8. Pre-identify all upstream and downstream dependencies that are critical to your operation.
9. We can do a better job protecting some critical infrastructure but you can't be protected from all threats.
10. Effects of climate change unknown.
11. Mitigation measures need to consider future O&M needs.
12. Can't do anything without the fuel and electrical grid.
13. Store emergency equipment off site (i.e. generators, pumps etc) so they don't get damaged as well.
14. Expect latent damage to systems and infrastructure.

Appendix H: Abbreviations and Acronyms

ADA	American Disabilities Act
CCM	Cultural Consensus Model
CENAD	Corps of Engineers North Atlantic Division
DIR	Port Director
ERDC	U.S. Army Engineer Research and Development Center
ES	Environmental Specialist
FEMA	Federal Emergency Management Agency
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
SLR	Sea Level Rise
SP	Safety Planner
USACE	United States Army Corps of Engineers (U.S. government)
USCG	United States Coast Guard

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
yards	0.9144	meters

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14. ABSTRACT
Numerous decision-making barriers prevent or delay climate and extreme weather resilience investments. Port decision-makers' perceptions of such barriers are important for proactive strategies for reducing coastal vulnerability and supporting safe and sustainable operations of U.S. ports. This report identifies the perceived adaptation barriers for seaports, and strategies to remove them. Interviews with 30 directors/managers, environmental specialists, and safety planners at 15 medium- and high-use ports of the North Atlantic resulted in a typology of factors and conditions that hamper adaptation actions, planning, and perceived strategies to overcome these barriers. This study finds that the decision-makers have consensus on seven overarching barriers to adaptation: the lack of understanding of the risks (93%), lack of funding (77%), perceived levels of risks do not exceed the action threshold (70%), governance disconnect (67%), physical constraints (67%), lack of communication amongst individuals (7%), and the problem (of adaptation) is overwhelming (7%).For strategies to overcome the adaptation barriers, the study points to the importance of fostering collaborations, making regulatory changes, and conducting risk assessments. Port decision-makers also mentioned the need for developing financial incentives and taking advantage of communication networks as necessary strategies to implement climate and extreme weather adaptations.

15. SUBJECT TERMS
Climatic changes—Risk assessment, Harbors, Inland navigation, Navigable waters, Navigation, Waterways

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